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Energy Efficiency Analysis of Residential Electric End-Uses: Based on Statistical Survey and Hourly Metered Data

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Since 1995 Automatic Meter Reading (AMR) technology has been installed in Finland creating third party (monitoring and research) access for all customers. By the end of 2013 at the latest, almost all electric consumption will be measured hourly. Beyond billing facilitation AMR meters have provided a great deal of opportunity for energy efficiency analysis. This thesis uses data from AMR meters and statistical data collected from questionnaire to evaluate efficiency and energy saving factors.

Two databases were established for statistical and hourly power consumption data from Kajaani, Savo and Vantaa area households. MySQL 5.1 was used for data storing and MATLAB and Excel were used for data analysis.

Due to some information shortage and low number of households in a group formed for comparison, the results of the analysis are limited to the larger household consumptions. The minimum number of households in a group prepared for comparison is limited to six. Supportive theoretical calculations and comparative explanations are provided for relevant analysis results.

For the majority consuming electric end-uses, error analysis is included to support clear interpretations of results. The results from this study are also used for an online balance sheet calculator which is expected to imply the combined effect of various electric end-uses on the whole consumption of households. Moreover, the explained procedure can be used as a reference for power companies and researchers to utilize hourly metered power consumptions for household load monitoring and efficiency analysis.

Keywords: Energy efficiency, residential electricity consumption, hourly power, AMR, heat pump, heating, ventilation

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Sitten vuoden 1995 etäluettavia sähköenergiamittareita on asennettu Suomeen. Kaukoluettavuus on mahdollista kaikilla asiakkailla vuonna 2013. Tarkemman laskutuksen lisäksi etäluettavamittaus luo mahdollisuuksia tarkempaan energiatehokkuusanalysointiin. Tässä diplomityössä käytetään etäluettavien mittareiden antamaa tietoa yhdessä kyselytutkimus aineiston kanssa arvioimaan tilastollisesti kohteiden tehokkuus ja sähköenergiansäästö mahdollisuuksia.

Kaksi tietokantaa perustettiin aineistolle Kajaanista, Savosta ja Vantaalta. Toinen oli kyselytiedoille, ja toinen tuntimittausaineistolle. Tietokantaohjelmistona käytettiin MySQL 5.1 ja tietojen analysointiin käytettiin MATLAB ja Excel-ohjelmistoja.

Jotta pystyttiin saamaan tarpeeksi asuntoja verrokkiryhmiin, valitut ryhmät keskittyvät suurempiin asuntoihin. Minimimäärä asuntoja ryhmässä oli kuusi. Analyysin tueksi suoritettiin teoreettisia laskuja sekä pohdintoja tulokseen vaikuttavista tekijöistä.

Olennaisiin tuloksiin on tehty virhe-analyysi tukemaan tulosten selkeää tulkitsemista. Tämän työ tuloksia käytetään web-pohjaisessa energiansäästölaskurissa ja arvioissa kotitalouden kokonaiskulutukseen vaikuttavien tekijöiden vaikutuksesta sekä niiden keskinäisistä suhteista. Sähköyhtiöt voivat käyttää työn luomaa rakennetta lähtökohtanaan rakentaessaan etäluettavien mittarien pohjalta seurantatyökaluja ja energiatehokkuusanalyyseja kotitalouksille.

Avainsanat: Energiatehokkuus, kotitalouskulutus, tuntiteho, AMR, lämpöpumppu, lämmitys, ilmanvaihto

Preface

This Master's thesis has been done at the power systems laboratory of Aalto University School of Science and Technology as part of the ENETE(energiatehokkuuden kehittäminen energiayhtiöiden toimin)project. The research was funded mainly by the Finnish Funding Agency for Technology and Innovation (TEKES) and also other power companies and public institutions.

First of all, I would like to sincerely thank my supervisor Matti Lehtonen for his deep interest in the research subject and for his encouragement and vital support. For his friendly and helpful advice in every step of the research, I thank my instructor Anssi Ahola. Many thanks to Jari Rusanen(E.ON Kainuun Sähköverkko Oy) for the continued support on the consumption data and to members of the steering committee for the intense discussions during the project. I thank William Martin for proofreading of the final manuscript.

I would also like to thank mom and dad for many reasons.

Otaniemi, 22.03.2010

Merkebu Zenebe Degefa

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List of symbols and abbreviations

Symbols

C	mass constant (kWh/^{o}C)
$\triangle T$	temperature difference in settings before and after the pick-up T_i - T_{i-1}(^{o}C)
P_{tot}	total installed heating capacity (kW)
$U \times A$	overall loss coefficient (kW/^{o}C)
T_{set}	pick-up set point temperature Ti (^{o}C)
T_{out}	outdoor temperature (^{o}C)
UA	overall loss coefficient (kW/^{o}C)

Abbreviations

IPCC	Intergovernmental Panel on Climate Change
AMR	Automatic Meter Reading
GSHP	Ground Source Heat Pump
ASHP	Air Source Heat Pump
COP	Coefficient of Performance
HDD	Heating Degree Days
EHPA	European Heat Pump Assosiation
IEA	International Energy Agency
ASHREA	Advancing HVAC&R to serve humanity and promot a sustainable world

1 Introduction

Unlike any other time in recent history, global warming has put the existence of mankind in danger. According to the report from the IPCC, global surface temperature increased 0.74 $\pm$ 0.18 ^{o}C between the start and end of the 20th century. As the scientific documents justify the main facilitators for heating our beautiful world are greenhouse gases emitted from the chimneys of industries. Since the problem came to our awareness, the international community has been taking various measures, though not encouraging enough. Among those larger actions, the European Commission 20-20-20 target is an ambitious one. According to the agreement, a 20% cut in emissions of greenhouse gases is expected by 2020. As part of the EU 2020 plan, the government of Finland has approved a strategy, on 6 November 2008, with detailed measures to be taken. The national measures which specifically focused on enhancing efficiency of energy consumption on housing, construction and transportation are expected to reduce emissions by an average of 16% from the 2005, by 2020.

On the other hand, the growing installation of AMR meters open wide the opportunity for energy monitoring and detailed consumption analysis for efficiency. In Finland, consumption places that are equipped with main fuses of over 3 x 63A must have hourly metering and by the end of 2013, 80% of all customers will be metered with AMR. This study, focusing on household consumption, evaluates saving potentials and efficiencies of electric appliances using data from hourly AMR readings of the Kajaani and Savo areas of middle Finland.

1.1 Significance of household consumption in Finland

The energy saving potential of end-use sectors in the EU-25 residential households accounts for an estimated 27% of the total 2020 target savings. In Finland, heating is the giant predator accounting for above 40% of household electric power consumption. Besides households in Finland are equipped with standard equipment where well above 70% of households own microwave ovens, freezers and dishwashers. As the above numbers tell, implementing informed energy saving policies on residential households in parallel with awareness creating programs will have a significant result. There have been various calculation mechanisms for energy saving potentials of individual appliances and the whole household as well. This study, unlike most previous research, evaluates electric energy saving potentials and efficiencies of individual appliances based on hourly metered power consumption incorporated with survey data.
In Finland, the annual average temperature changes from +6^{o}C in the southern coastal area to -2 ^{o}C in the north of Lapland. Due to this extreme winter temperature, according to the Odyssee database[29], Finland is the top kWh consumer per dwelling in Europe. Based on report from Motiva Oy, the shares of heating fuels in households are district heating 37%, Small-scale wood combustion 22%, electricity 18%, oil 17%, heat pumps 5%, and others 1%. Therefore, monitoring and evaluating

various heating systems will take the most part of the energy saving potentials, as this study did. The heating season extends from September to May leaving the

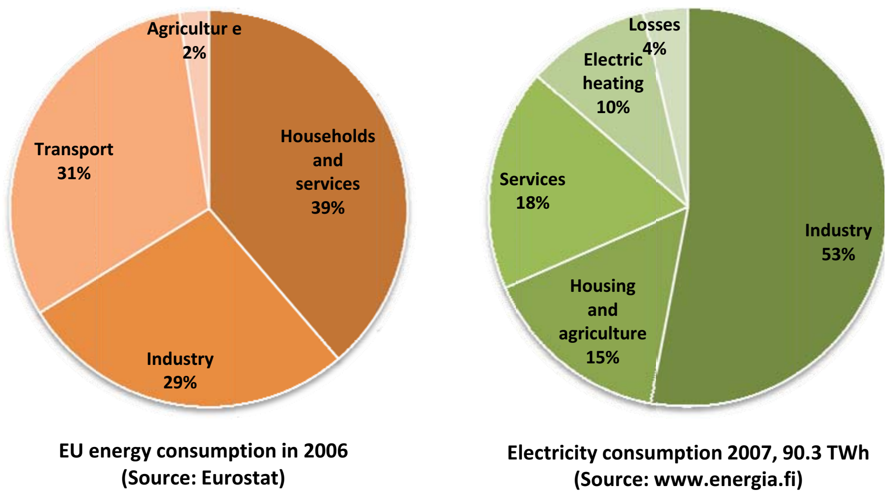


Figure 1.1: EU energy consumption in 2006(left), Electricity consumption of Finland (right).

cooling season to be insignificant. As with all other European households, lighting, cold appliances and electronics following as the next main consuming groups. A

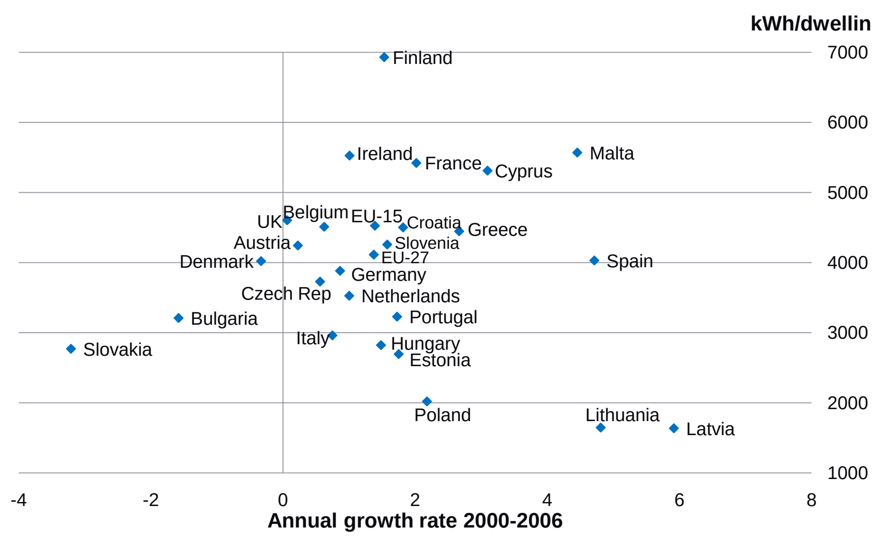


Figure 1.2: Electricity consumption per dwelling: annual growth and present level (2006). [29]

study by Adato Energy Oy quantifies the electric power consumption of grouped end-uses for 2006. Non-electric heated single-family houses are considered in the process.(Table 1.1)

Table 1.1: Household electricity use by appliance group for 2006. [1]

Appliance group	GWh 2006	Percentage
Cold Appliances	1461	13%
Cooking	653	6%
Dish washer	261	2%
Washing and drying	391	4%
Entertainment	834	8%
Information technology	407	4%
Electric sauna stove	852	8%
HVAC(1)	621	6%
Comfort floor heating (2)	206	2%
Car pre-heating (3)	218	2%
Indoor lighting (4)	2427	22%
Outdoor lighting	89	1%
Other	2572	23%
Total	10992	

(1) ventilation, circulation pumps, heat distribution centers

(2) excluding electrically heated buildings

(3) includes only single-family houses

(4) estimated for 2006 using the distribution in 1993.

1.2 Common measures of energy saving

In previous times assessments for energy efficiencies were used to be done for individual appliances. As a result, policies and regulations from government focused on separate solutions to the studied problems. In the process the interdependency of household appliances in factoring the gross household CO2 emission was not given much attention. This study, using hourly metered household consumption, evaluates combinational influences such as heating vs. ventilation, heat replacement factors and household heated area vs. various systems. Some of the most recent energy efficiency measures, as of 2007, in residential sector are listed below.

1. *Energy labeling scheme for windows*
   Finnish window manufactures covering 80% of the total windows market in Finland energy labeled their product voluntarily.

2. *The thermal insulation ordinance*
   First of its kind in its holistic approach; rather than only capping the losses by individual parts of the building shell. This regulatory approach considers building air tightness and air recovery ventilation systems at the same time.

3. *A household tax deduction*
   Deduction of 60% of the labor costs is incurred in replacing, upgrading and repairing the heating systems of small residential houses.

4. The Hylä III Energy Conservation Co-operation Program on promoting energy conservation in Oil-heated properties. It targets promoting renewal of old oil-heating systems and combination of renewable with oil-heating.

The reason why recent measures are listed above is to give insight how the output of this study might be implemented and; moreover, to show what the usual approaches look like. The overall shape of this Master's thesis can be visualized in the following bounded targets and features.

a. Hourly power consumptions of individual households metered by AMRs is used for energy efficiency analysis

b. Practical efficiencies and saving potentials of individual appliances are assessed

c. Combinational effect of end-uses on the gross household consumption is analyzed

d. Factors are evaluated from database groupings for online balance sheet application with recommendations for energy saving actions.

Hopefully, this study will assist new approaches towards energy saving actions in residential sectors.

2 Analysis and interpretation Principle

The introduction of smart meters in recent years provided a great deal of opportunity to look into detailed consumption profiles of households. Nevertheless, deciphering the hourly metered consumption without additional information from the specific household is impossible, at least from a data analysis point of view. Incorporating survey data with the power consumption will enhance effective interpretation. During the process of this study, a consumption and survey database has been built and filled with data.

2.1 Survey data

The main purpose of survey data is to group households of similar profile later in analysis of power consumption. The first thing done in the project is getting the addresses of households from Kaajani, Savo and Vantaa area where they have already installed AMRs. In survey database addresses of 7861 households from Kaajani, 3561 households from Savo and 4859 households from Vantaa towns have been stored. The next step was preparing a questionnaire with detailed possible information fields to be filled and sending it to the 16101 households.

2.1.1 Questionnaire preparation and grouping

In preparing survey data questions, the following points were considered

1. The understandability and preciseness of the questions

2. Relevance and length of the question

3. Appropriate answer type for later data analysis.

With all the above considerations it was particularly challenging to minimize the number of questions. Due to the nature of the study and need for information, the prepared questions became a little too long. The questions were grouped into four major groups such as background information, heating and ventilation systems, electric appliances and electric consumption habits. The final household questionnaire is contained in Appendix I.

2.1.2 Collection and data handling

The expectation of return among sent questionnaires was about 30% based on previous experiences. What we got was 2063 from Kajaani, 869 from Savo and 898 from Vantaa. A below expectation 23.8% of households sent back the filled questionnaire. All data collections and data insertion was completed in the summer time of 2009. A Visual Basic program connected with a MySQL database was prepared in exact format with the paper questions. This way, data insertion was facilitated enormously. There were some questions termed as 'deal breakers' without which the data analysis will be meaningless. 'Type of primary heaters' was one of these defining questions. During data entry, filtering was done based on the stated criteria.

2.2 Hourly metered household consumption

Automatic Meter Reading (AMR) reads real time power consumption using an already established GSM based mobile network. An AMR meter consists of an energy meter, collector Unit and communication module.

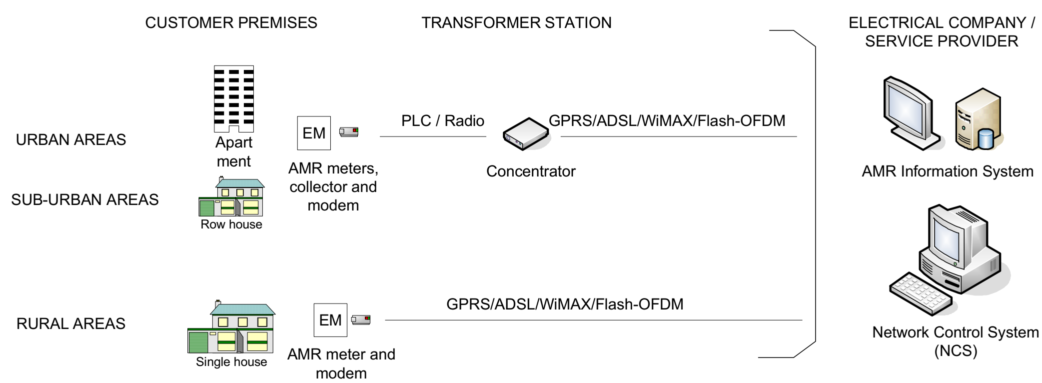


Figure 2.1: The two communication layout types of AMR system (2006)

When we receive the data from E.ON Kainuun Sähkverkko Oy, the stored data consisted not only of meter id, hourly consumption and time of measurement but also 8 bit validation data.

Table 2.1: Information carried by 8 bit validation data.

Bit No.	Meaning
1	Clock error
2	During measurement error
3	Power depletion
4	Incorrect value of the request
5	Error reading external drive
6	Estimated
7	Edited manually
8	Calculated on the basis of incomplete information

For every bit, '0' stands for normal situation while '1' flags the stated happening. After we got data from both Kaajani and Savo areas, data treatment and checking was done. That includes

1. Removing households without consumption due to late installations of meters
2. Rearranging all year consumption to winter time avoiding DST consumption shifts.

2.3 Database interrogation

The establishment of survey data and consumption data lead to availability of grouping and analysis. The two databases have a common primary key which is the meter id of the specific household. For every hypothesis to be tested, an exclusive query will be written to sort out the specific issue. In the process, the minimum number of households in a group for comparison is set to be six. The query is rewritten rigorously until it is believed to represent the unique case. The general process of the analysis method is shown in the flow chart presented in Figure 2.2.

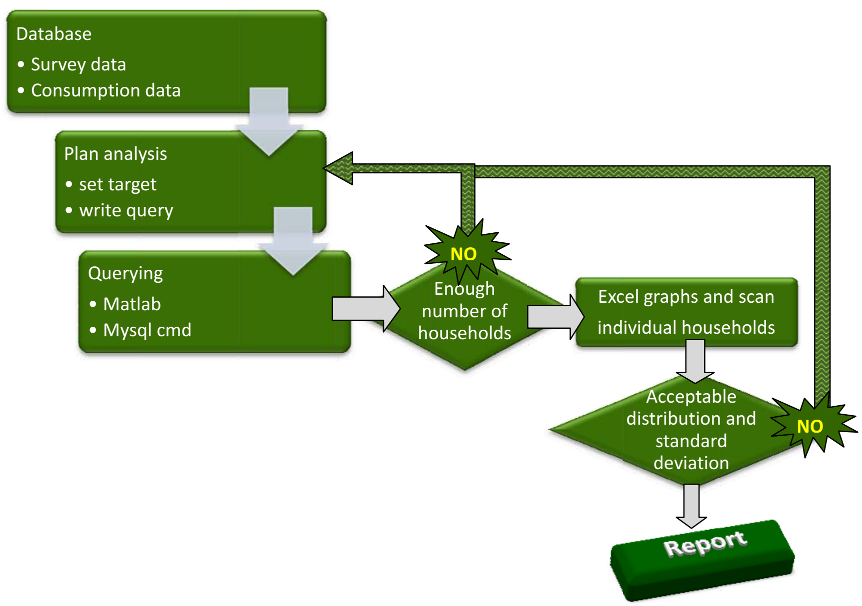


Figure 2.2: Overview of database interrogation process

2.3.1 Software and programs involved

The database is built using MySQL-essential-5.1.31-win32 and with its ODBC connector and GUI tools. In the analysis phase, two querying capable MATLAB GUIs were programmed for graphing and for calculations of daily and yearly consumptions. Each household has 8760 consumption data in the case of Kaajani households for the time span from 01-07-2008 to 30-06-2009. In the case of Savo households, the consumption year is 2008 with 8784 data point each.

Besides graphing and calculations with the data analysis tool of MATLAB, further treatments were also performed with excel 2007. Excel was used for regressions, correlations, and error calculations. In exporting and importing grouped data MySQL cmd line played vital role.

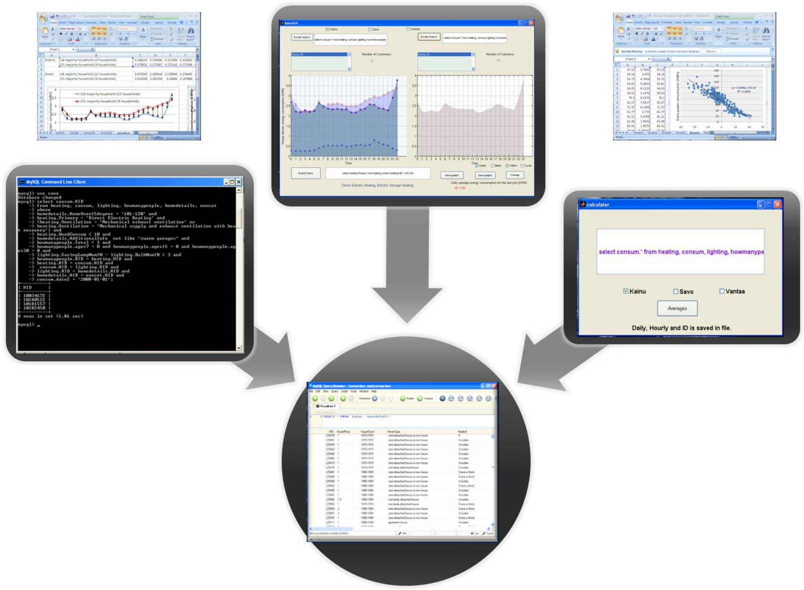


Figure 2.3: Applications for querying and processing data

Complete manual of database querying and cd copy of programs with full data will be incorporated at the end of this thesis.

2.3.2 Interpretation of results

For two groups of households where the standard deviation of consumption inside a group is minimum, the variation of consumption is then attributed to the initially targeted hypothesis. The numbers stated as a result are therefore in some margin of errors. Though there is strong believe that the results of the analysis are implying the original idea behind it, before referring to it as the sole representation of the situation, separate individually-based experiments are recommended. When percentage results are given sometimes they represents from the specific end-use consumption and other times they may represent from the total household consumption. It will be stated in the respective cases. Sometimes explanations given in this thesis should be viewed from an energy consumption perspective since the technicalities of the issues have broad dimensions.

2.3.3 Possible shortcomings

The number of households attained from the survey dwindled further due to lack of full year hourly metered consumption data and other reasons. Of course, we have a significant number of cases in our database to start analysis, but it was not so easy to query out though. The following issues could be stated as obstacles that impeded the analysis process.

1. Very small number or unavailability of households in a given specific group. Compromise was crucial between querying criteria and number of households available

2. Unanswered questions from survey data

3. Power marketing trend with cheap night time pricing, which distorted the daily consumption structure. Even households other than those use electric storage heaters use this cheap price power.

3 Energy efficiency analysis of the major household appliances

3.1 Ground source heat pumps

The heat pump technique is a pretty old method used to reverse the natural heat flow from high temperature to low temperature. The most popular implementation is the refrigerator which absorbs heat inside the compartment with its evaporator coil to the outside environment so that inside remains cold at the required temperature. To accomplish the pumping job, heat pumps need energy which is relatively small in quantity compared to equal heating or cooling capability. In general, heat pumps transfer heat by means of circulating a refrigerant fluid around a compression-expansion cycle. We have two types of heat pumps named Ground Source Heat Pumps (GSHPs), a loop of pipes buried in the ground to remove or absorb heat for heating and cooling, and Air Source Heat Pumps(ASHPs) , which uses air as a heat source or sink.

Air Source Heat Pumps as primary heaters in Finland are not as feasible as GSHPs due to the extreme outside temperature drop during the winter season. But with little change on outside air temperature, the earth stores heat supplied from the radiation of the sun. In Finland, temperatures in the soil at 1m depth vary between $+2^{o}$C to $+12^{o}$C in the southern part and -2^{o}C to $+12^{o}$C in the northern part of the country. For small family houses, country farms and even for small community district heating, heat pumps could be utilized to make ground stored heat available. To pump heat from ground temperature to the higher household temperature (which is 20 ^{o}C in Finland), heat pumps use circulating refrigerant fluid around a compression-expansion cycle. Mostly an ethanol-water solution is used as the heat exchange fluid (refrigerant).

The basic working principle can be explained in the following three steps:

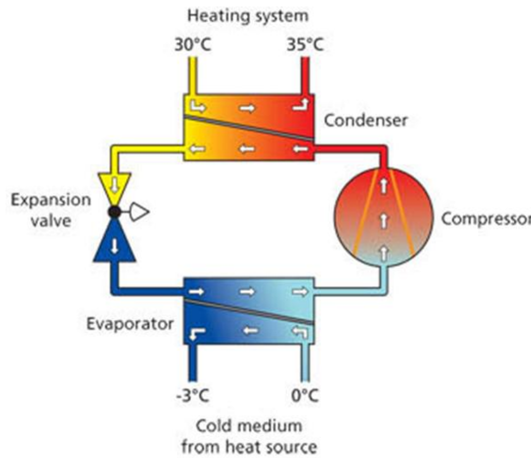


Figure 3.1: Heat pump main components

1. The refrigerant whose boiling temperature is below 0 ^{o}C boils as it passes through ground where it absorbs heat
2. Now the boiled refrigerant vapor passes through a compressor which is powered by electric energy. As the pressure of the gas increase, its temperature also goes up to a temperature greater than room temperature
3. Then the refrigerant passes through a heat exchanger, condenser; where heat flows to the room by the process of condensation of the refrigerant vapor
4. The process closes the loop after the refrigerant passes through an expansion valve where it returns to a low temperature liquid to be boiled by the ground temperature.

3.1.1 Types of ground source heat pumps

Ground Source Heat Pumps could be closed loop, which has three arrangements itself, or open loop. The classification mainly depends on the orientation of the heat exchanger tubes inside the ground or water surface.

1. *Closed loop system*

   a. *Horizontal*
   Composed of pipes that run horizontally just below 1-1.5m depth in the ground. Due to its half excavation cost compared to vertical orientation, it is the most used one if there is enough land space. About 70% of heat pumps in Finland are horizontal ground coupled systems.

   b. *Vertical*
   The U-shaped plastic installed in boreholes vertically 80-130m deep. These types of installation are used in a case where the horizontal installation becomes unreasonably large in accordance with the size of area to be

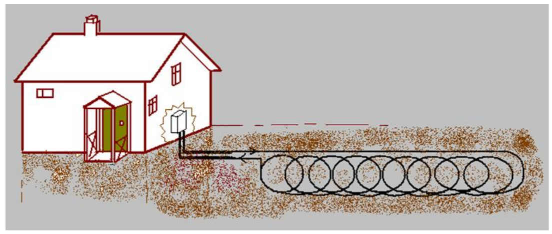


Figure 3.2: Horizontal GSHPs.

heated (like hospitals and schools). About 10% of heat pumps in Finland are vertical ground coupled systems.

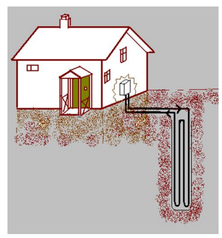


Figure 3.3: Vertical GSHPs.

c. *Pond and Lake Loops*
To insure that natural temperature variations at the bottom are low, pond and lakes for this purpose are expected to be 3m deep at least. In Finland, about 20% of heat pumps are of this type.

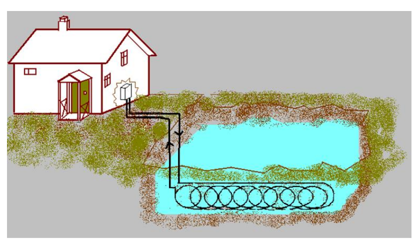


Figure 3.4: Pond GSHPs.

2. *Open loop system*
An example of this type of heat pumps is the 0.5MW district heating (of which 50% covered by GSHPS) installed in Forssa, southern Finland. Water is pumped in from a shallow aquifer with 7^{o}C temperature and pumped out with a temperature of 2-4 ^{o}C after passing through the heat pump cycle. The issue here is the purity of the discharged water which has to meet environmental standards.

Based on the European Heat Pump Association (EHPA) 'our vision 2020' report, the contribution of heat pumps towards the total ambitious goal is shown in Table 3.1.

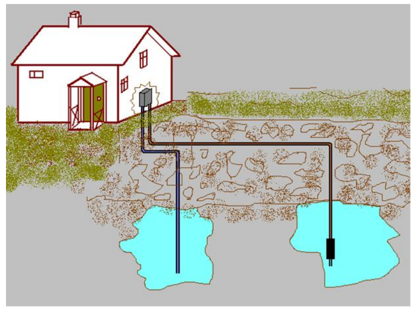


Figure 3.5: Open loop GSHPs.

Table 3.1: Contribution of heatpumps on EU 2020 energy efficiency target.

EU energy targets for 2020	EU target	Change required to reach target	Potential contribution by heat pumps	As share of the EU target
Primary energy consumption	Reduction by 20%	4.385 TWh	902 TWh	20.6%
Renewable energy production	Contribution of 20% by RES	3.508 TWh	774 TWh	22%
Greenhouse-gas-emissions	Reduction by 20%	1.073 Mto	230 Mto	21.5%

Expectations from heat pumps are huge as the numbers in Table 3.1 tell. Evaluation of actual savings from heat pumps in real world applications and improvement of efficiency is necessary in order to meet the 2020 target. The efficiency of heat pumps is expressed as Coefficient of Performance (COP) which is highly dependent on both the source and emitter temperatures.(Figure 3.6) Therefore, using a low heat distribution temperature results in high COP.
COP = Produced heat/Used electricity
In the development of heat pumps for the last 20 years the COP of ground source heat pumps increased from an average value of 2.5 to 4.5. In Finland, the installation of heat pumps is increasing significantly from year to year. According to the 2009 EHPA report on European heat pump statics, in Finland, the heat pump market grew by 30% in 2008 compared to 2007.

3.1.2 Data analysis and results

1. *Statistical summary and analysis methodology*
   To give general overview of our database, the following list of information is provided. General observations:

   a. All houses with Ground Source Heat pumps as primary heaters are one

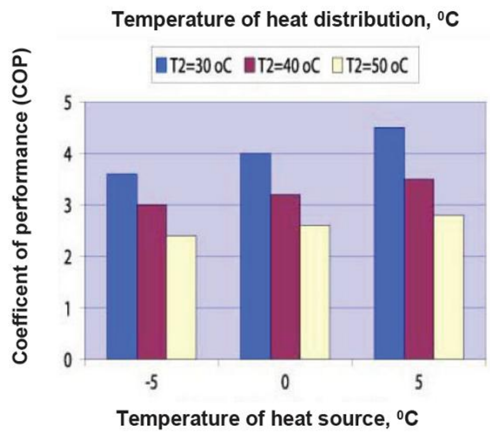


Figure 3.6: COP and heat source temperature relation.[9]

family detached houses

b. 72.5% of houses with GSHP as primary heaters are constructed from wood

c. Almost all houses with GSHP as primary heaters use Wood heating (e.g. storing fire place) for supportive heating

d. Number of houses using GSHPs as their primary heaters grouped under their heated area of over 15 degree is plotted in Figure 3.7.

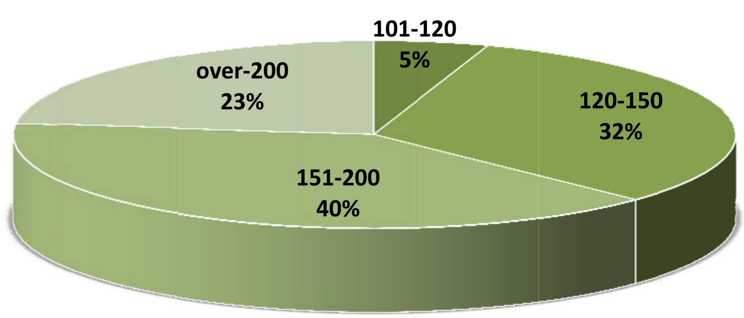


Figure 3.7: GSHPs in statistical database grouped under heated area.

In this analysis we will evaluate the efficiency of GSHPs mainly by comparing them with the direct electric heaters. To separate heated and non-heated seasons clearly, from January to March, and from June to August, are taken as representing of winter and summer times respectively. The average consumption of each hour was evaluated for the two periods, arriving at 24 hour consumption of average hours, in order to give average daily consumption. After curve fitting on the 24 hours consumption, the area under the curve was evaluated, giving the daily average energy consumption. The assumption here is the difference between the average daily energy consumption of winter and summer mainly imply the heating consumption.

The above calculation was done for the three main heated area groups with GSHPs and Direct Electric heaters as their primary heaters. Also, supportive heating of wood heating was taken as criteria for those households included in the comparison. Possible shortcommings of this approach might be:

i. Very low number of customers in a group as we increase the criteria

ii. There is an increase in lighting consumption with the same trend as heating consumption

iii. Some answers in the questionnaire might be misunderstood which might give a completely different consumption trend from other customers in a group.

Nevertheless, we tried to clear as much as possible, for instance, by identifying summer cabins and unreasonably high or low consumption unlike to the speicific information in the statistical database.

All the above said, the data analysis ended up with the following results.

i. GSHPS saves 27.45% to 47.0% of DE heater consumption

ii. The saving increases with increment of heated area and households with a heated area of 151-200 sqm were the most benefited.

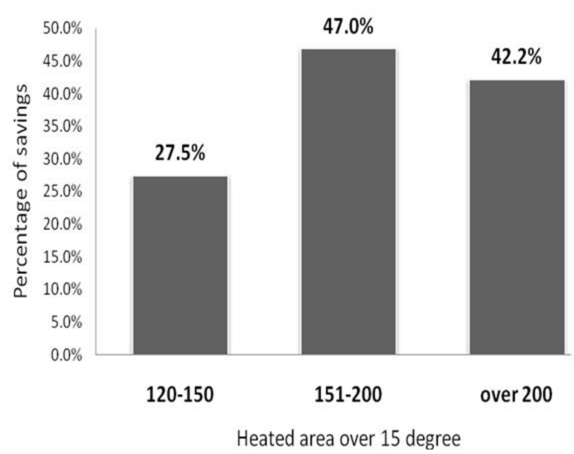


Figure 3.8: Savings of GSHPs compared to DE heaters.

2. *Error calculation for the analysis method*
Standard deviation by definition tells the average deviation from the mean of distribution. For two groups prepared for comparison, if their standard deviations are low, or they have similar standard deviations, then their average will be trusted to represent the group. For the case of ground source heat pump analysis, the standard deviations of their yearly consumptions stayed within

4-6MW standard deviation except for a direct electric heated household group with a heated area of 151-200 sqm. The heated area group, whose actual yearly consumptions scatter is plotted in Figure 3.9, has the worst deviation as it is shown on a standard deviation plot in Figure 3.10.

The next is the confidence interval of the mean heating consumptions used

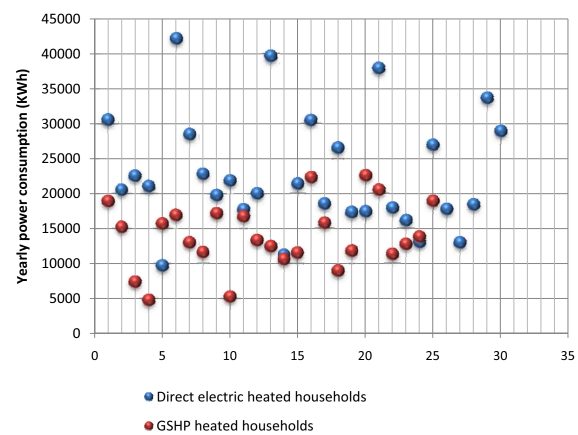


Figure 3.9: 151-200 sqm heated area scatter plot of yearly consumption.

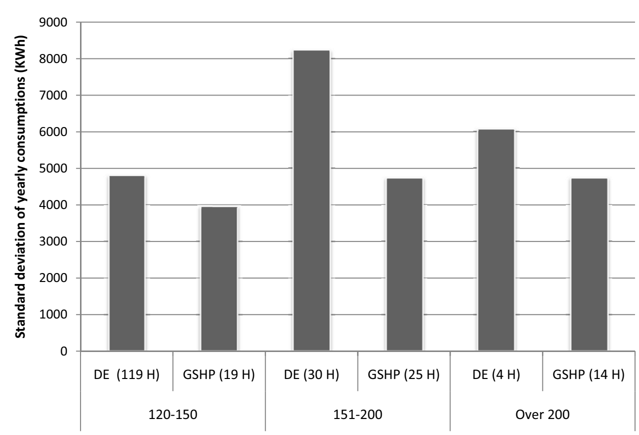


Figure 3.10: Standard deviation from yearly consumption for each groups made in GSHPs analysis.

for percentage saving calculations under each heated area groups. Due to the variation probabilities of consumption in households, a confidence interval of 90% was chosen for showing the saving potential calculation. Therefore, a 90% confidence interval means that 90% of all households actual savings lie between the calculated interval.

3. *Assessments and explanations of results*
According to the results of our analysis, the Coefficient of Performance of

Table 3.2: 90% confidence interval for saving potential.

Heated area (sqm)	90% confidence minimum saving	90% confidence maximum saving
121-150	13.43%	49.00%
151-200	38.97%	70.10%

GSHPs dropped from the usual manufactures' claim of 70%. The savings calculated in the analysis ranges from 27.5% to 47% over conventional electric resistance heaters. This situation compelled us to examine the calculations more clearly and also to make other analysis based on the detail consumption profile of the GSHPs. Potential reasons for lower COP values of GSHPs could be:

a. Frequent involvement of supplemental electric resistance heater
b. Performance would be good if GSHPs have operated through a complete cooling and heating season In Finland the cooling mode is not used much and therefore the total COP may fall from the claimed value
c. Our method of analysis, where the different in consumption from average winter day to average summer day assumed to be heating consumption, may be compromised by other unseen factors.

The major electric power consuming components of GSHPs are listed below.

(i) The compressor (Wc)
(ii) The brain circulating pump (Wbp)
(iii) The water circulating pumps (Wwp)
(iv) The heat pump circulation fan (Wf)
(v) The supplementary heating (Wsup).

Therefore, the total electric power input of the heatpump is given by

$$W = Wc + Wbp + Wwp + Wf + Wsup* \tag{3.1}$$

There are two performance factors used to explain the efficiency of ground source heat pumps interchangeably. The coefficient of performance (COP) is the delivered heat power divided by the supplied electricity to the heat pump compressor.

$$i.e. COP = Qh/Wc \tag{3.2}$$

On the other hand, the heating seasonal performance factor (SPF), some also call it COP$_o verall$, is the heat delivered from the heat pump divided by all the supplied electricity in the system.

$$i.e. HSPF = Qh/W, [7] \tag{3.3}$$

(this is the value we may calculate from the consumption data)
The seasonal performance gives a better understanding of the heat pump compared to the COP. The power consumption of the pumps totally depends on the length of the circulating tubes or the depth of the ground source installation. Moreover, the consumption of the supplementary heating is also highly dependent on the type of thermostat setting and yearly outside temperature of the specific household. Either manufacturers or researchers should do a feasibility assessment and make calculations of coefficient of performance (whichever name it has) for the specific installation environment. This study is limited in making performance analysis from the database in hand. To have a more

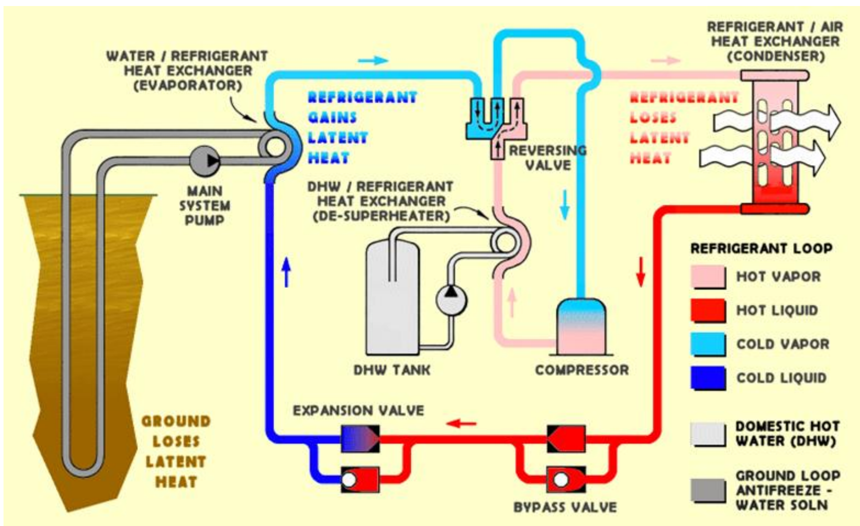


Figure 3.11: A typical ground source heat pump [27]

general idea of power consuming components distribution, the power ratings and capacities of a specific ground source heat pump studied in reference [7] is presented in Table 3.3.

In the same study the calculated values of the main power inputs are: power input to the compressor= 1211W, power input to the circulating pump = 65 W, power input to the condenser fan 140W and the total power = 1416W. It seems above 85% of the power consumption is that of compressors. Taking two households of similar profile except for difference in their primary heating type, we attempt to recalculate the heating coefficient of performance with supplementary heating.

If we calculate the overall heating energy savings from the rate of change of consumption for each degree centigrade temperature drop, we will get the following value:

$$Saving\% = (3.044 - 1.260) * 100/3.04 = 58.6\% \tag{3.4}$$

Assuming a 100% direct electric heater, we may calculate the heating season performance factor which is equal to 2.42. This is greater than the previously

Table 3.3: Power ratings and capacities of components of typical GSHP.

Main circuit	Element	Power ratings and capacity
Ground coupling circuit (2 circuit each 50m horizontal)	Water-antifreeze solution circulating pump	Three speed; speed step: (1250,1750,2250 rpm);Power(40,62,83 W)
Refrigerant circuit	Heat exchanger(air cooled condenser for heating)	3.77 kW
	Heat exchanger (between the brine and refrigeration fluid heat transfer for heating)	6.97 kW
	Compressor	The rated power of electric motor driving 1.4kW
		Refrigerant single phase capacity 4.279 kW
	Dryer	11.1-18.8 kW
Fan circuit	Fan of air cooled condenser	140W

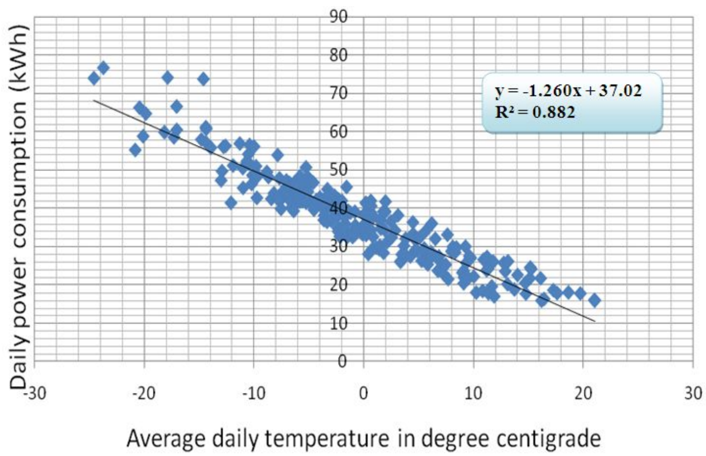


Figure 3.12: The scatter plot of ground source heat pump household for heated season days (from18-Oct-08 to 30-Jun-09).

calculated range (27.5-47%). In the process of interrogation of the database for detailed information, complete understanding of the requested thing is vital. One other way of validating the result is making a comparison with other related studies. The value we calculated is comparable with other northern countries which experienced lower performance factors compared to manufacturers claim for more than 3. In Canada, where air temperature can go below -30^{o}C, and where winter ground temperatures are generally in the range of -2^{o}C to 4^{o}C, earth-energy systems have a coefficient of performance (COP) of

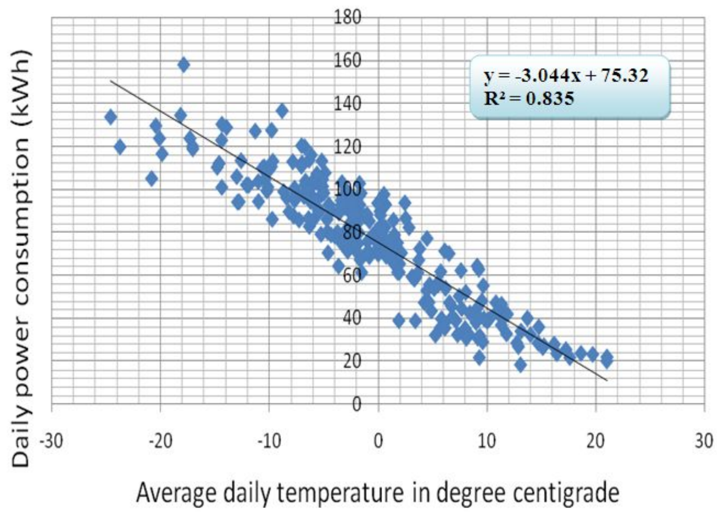


Figure 3.13: The scatter plot of direct electric heating household for heated season days (from18-Oct-08 to 30-Jun-09).

between 2.5 and 3.8.

In an extreme winter temperature environment, like Finland, the role of supplementary heating is of critical importance. As an example, according to a study in UK, for a two-story house of total floor area 288m2 a water-to-water heat pump with a rated capacity of 3.96 kW at an output temperature of 45^{o}C was installed. Additionally, an in-line direct electric heater (2x2 kW) was included to provide auxiliary heating. The auxiliary heater was consuming significant power in the lowest temperature months of the two years as shown in Figure 3.14. To study closely the operation of ground source heat

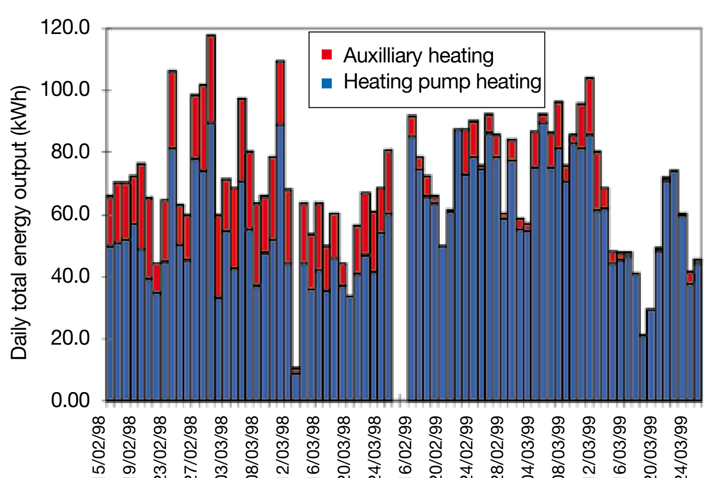


Figure 3.14: Auxiliary heater consumption of GSHPs.[26]

pumps, the hourly temperature and power consumption load curve is drawn in Figure 3.15. Moreover, we will try to figure out the role of supplementary electric resistance heaters from a single heating cycle in the case of extreme temperature heating. The four days of highly cyclic consumption and very low

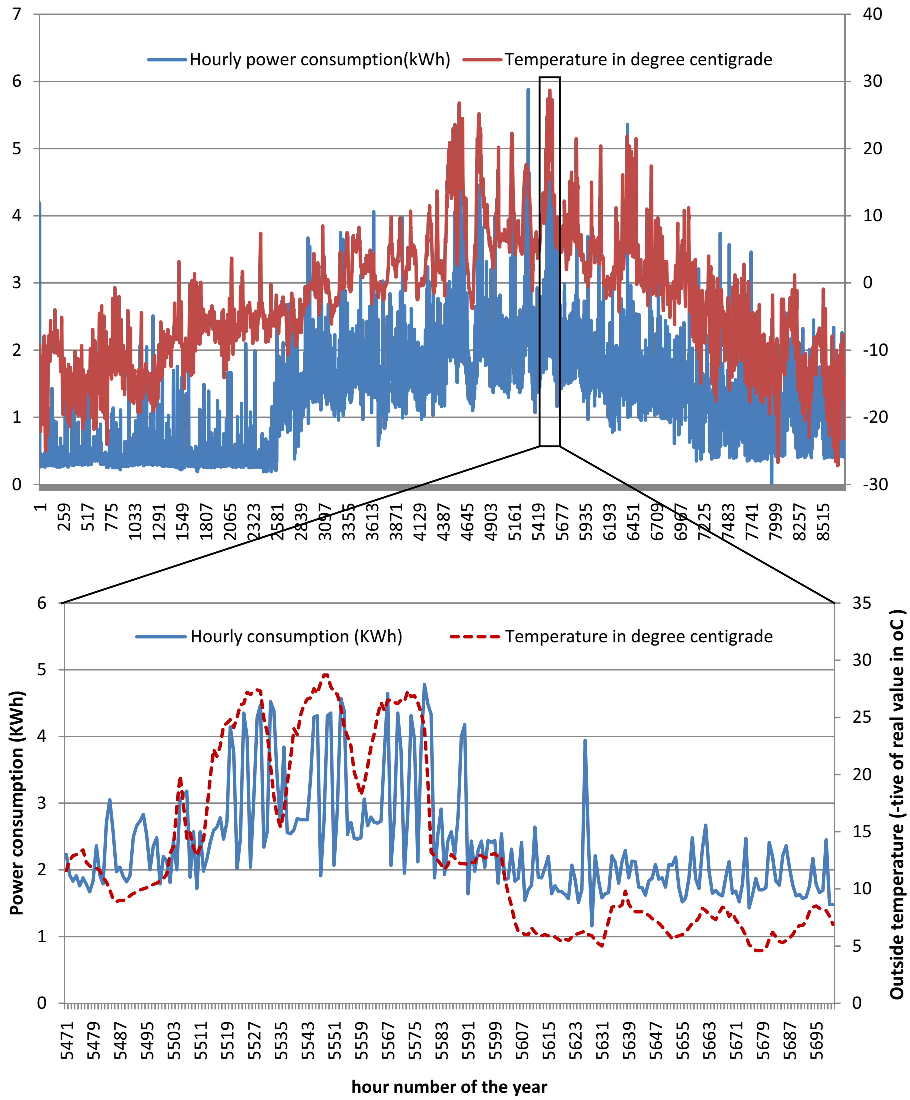


Figure 3.15: Winter time peak consumptions.

temperature shown in Figure 3.15 are drawn separately for detailed analysis. For a constant outside temperature drop below -25^{o}C the pure cycle is visible. Also the time, especially in the three days between 16/02/2009 to 18/02/2009, the temperature drop that occurred is in the time gap between 1am and 8am. Therefore, the consumption variation is affected solely due to heating system operation. A typical consumption cycle took 5 hours and the average cycle consumption is drawn in Figure 3.17. Actually, from the heating cycle shown above it is difficult to tell exactly the portions of supplemental electric resis-

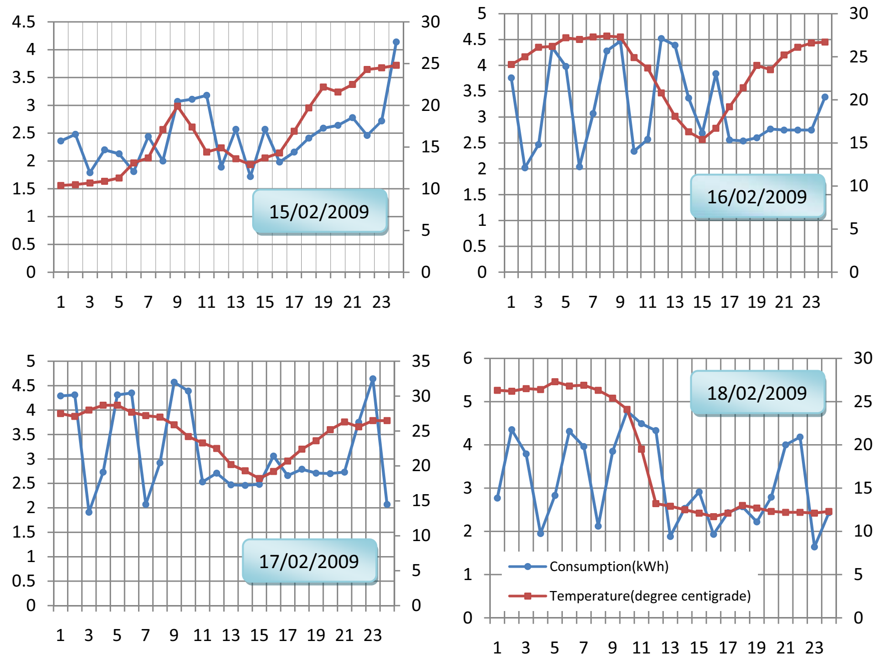


Figure 3.16: Four days winter time peak consumptions.

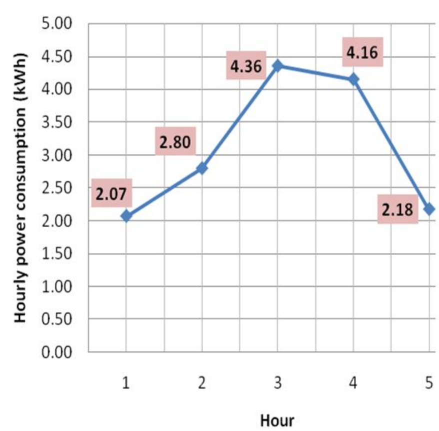


Figure 3.17: Consumption close-up for one heating of cycle of GSHPs.

tance heaters except to tell of their contribution to the overall consumption. We can see in the cycle that the electric resistance heater is turned ON on hour 2 and turned OFF on hour 5. Most heat pumps initiate their supplementary heaters when the net heat loss of building is greater than the capacity of the specific heat pump. Supplemental (Auxiliary) heaters could be of any kind as long as the thermostat controlling the heat pump could initiate it. Most of the times, these heaters could be oil, gas or electric heaters. A balance point for a typical air-source (although different for ground source) heat pump might look as shown in Figure 3.18. A conventional thermostat with set point T mostly

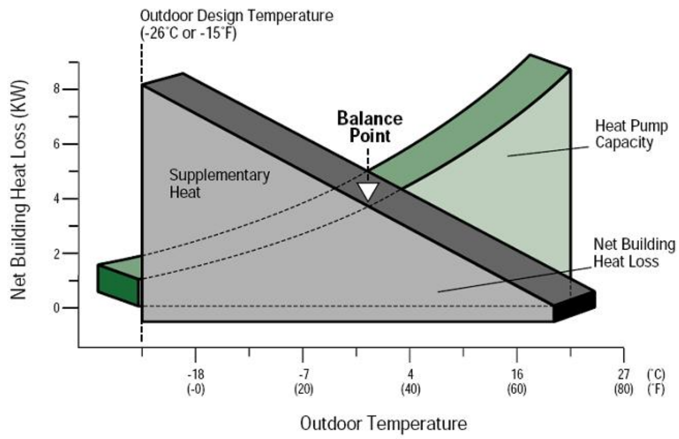


Figure 3.18: Balance point of heat pumps.[6]

works by turning ON the heater at T minus 0.5 ^{o}C and turning it OFF at temperature T plus 0.5 ^{o}C. In the case of heat pumps, the heat pump and the supplementary electric resistance heater will be set with on overlapping 0.5 ^{o}C gap. More conveniently, the supplementary heater will be set 0.5 ^{o}C lower just under the heat pump. For a thermostat of setting point 18 ^{o}C at night and 21 ^{o}C daytime, also with ramp starting to avoid unwanted operation of electric heaters, the daily program setting appears as drawn in Figure 3.19. According

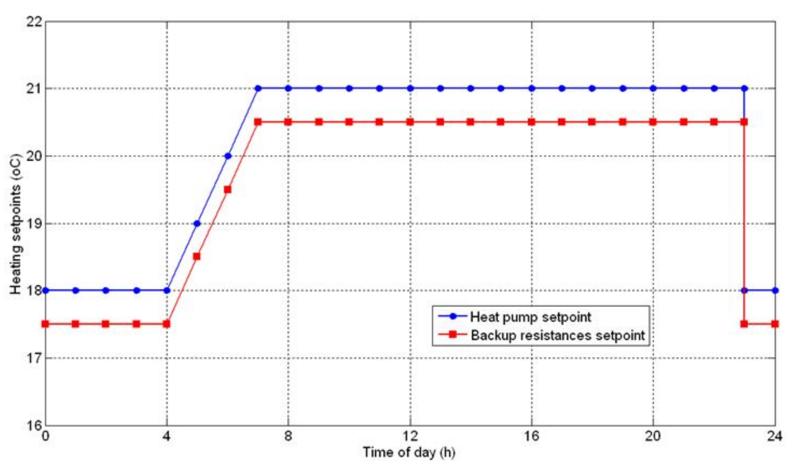


Figure 3.19: Recommended set-points of heat pumps and back up resistance heater thermostats.

to the typical thermostat with setting of room temperature 21^{o}C as explained in this paper, the two heaters work with in manner as shown in Table 3.4.

Usually, the supplementary heat is needed when the outside temperature is lower than the balance point temperature. The balance point of a heat pump is the outdoor temperature at which a heat pump's output exactly equals the

Table 3.4: Thermostat settings for GSHPs and supplemental heater.

Room temperature	$\leq 20.5^oC$	20.5 ^{o}C to 21 ^{o}C	21 ^{o}C to 21.5 ^{o}C	$\geq 21.5^oC$
Supplemental electric resistance heater	ON	ON	OFF	OFF
GSHP	ON	ON	ON	OFF

heating needs of the conditioned space.

$$T_{balancepoint} = T_{thermostat} - (Q_{internal}/(\sum (A \times U)_{Conduction+Infiltration+Ventilation})) \tag{3.5}$$

Usually it is about 1.5 ^{o}C. In Finland, in the analysis year 2008/2009, the outside temperature was below 1.5 ^{o}C for above 45% of the time throughout the year. According to our observations, the performance of ground source heat pumps dropped significantly from the claimed values. The need for specific performance calculations of heat pumps for specific locations in Finland is unquestionable. Based on detailed observations and literature reviews, the basic reasons for lower performance are the following

1. The ground source heat pumps were used mostly in the heating season
2. The need for supplemental heating was significant for extreme outside temperature of mid-winter
3. Insufficient survey information, where hot water source is not known clearly.

It is important that supplemental heat does not come on when it is not needed. There are two ways to prevent unneeded use of supplemental heat:

1. Outdoor thermostats sense the outdoor temperature and lockout the supplemental heat unless the temperature drops below a preset point
2. Certain microprocessor-controlled thermostats allow the heat pump to "ramp-up" to the desired temperature but will not turn on the supplemental heat unless the heat pump alone is unable to keep the home up to the desired temperature.

3.2 Air Source heat pumps

These heat pumps work exactly with the same principle as ground source heat pumps except the heat source or sink is outside air. Theoretically, the total heat supplied by heat pumps is the sum of heat absorbed from the air and the energy supplied to drive the cycle. Typical electric driven heat pumps might supply up to 100kWh of heat with input electric power of 20-40 kWh. They are more efficient in spring and

autumn than winter. Normally, they are coupled with direct electric heaters and act as supportive heaters due to temperature drop during the winter season.
There are two types of air source heat pumps:

1. *Air to Air heat pumps*
   It pumps heat from outside air and blows in to the room hot air (heating cycle).

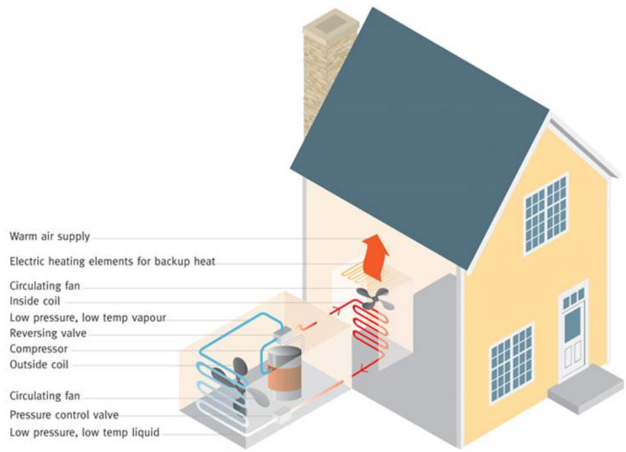


Figure 3.20: Typical air-to-air heatpump.

2. *Air to Water heat pumps*
   In this case instead of blast of hot air, water will be boiled in a cylinder connected to the heat pump. Afterwards, the heated water circulates mostly inside underfloor heating tubes or may also circulate through radiators and fan-assisted convective heaters.

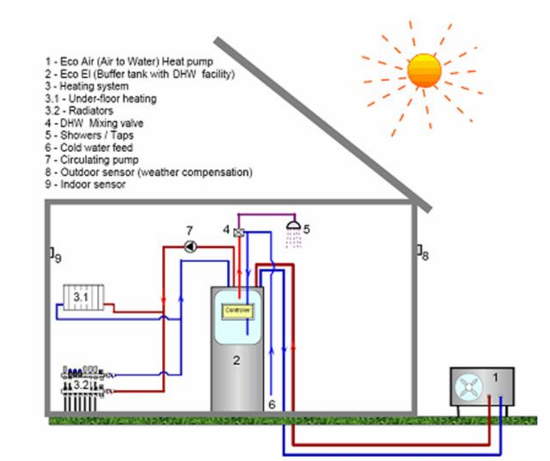


Figure 3.21: Typical air-to-water heatpump.

According to IEA heat pump center (http://www.heatpumpcentre.org/) , which Finland became a member of recently, various heat sources for heat pumps and their available temperatures are given in Table 3.5.

Table 3.5: Available heat sources for heat pump.

Heat source	Temperature Range (C)
Ambient air	-10 - 15
Exhaust air	15 - 25
Ground water	4- 10
Lake water	0 - 10
River water	0 - 10
Sea water	3 - 8
Rock	0 - 5
Ground	0 - 10
Waste water and effluent	≥ 10

The main reasons for including both capacity and coefficient of performance (COP) drop especially during heating season are frosting, defrosting and cycling. During the winter season the outside coil of air source heat pump will be covered with frost which insulates it from absorbing heat. To overcome this problem heat pumps run defrosting mode which pumps heat to the outside coil to melt and drain away frost. The problem here is for every defrosting operation heating will be interrupted and to keep inside house comfort constant, the integrated direct electric heater will start to operate. There might be different and efficient deforesting mechanisms but the fact

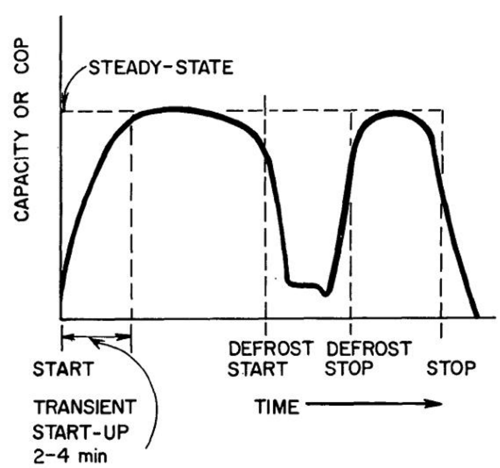


Figure 3.22: Typical heat pump cycle with defrost [14].

that performance of heat pumps decreases in the heating season remains as an issue. According to the IEA heat pump center "ambient and exhaust air, soil and ground water are practical heat sources for small heat pump systems, while sea(lake), river water, rock(geothermal) and waste water are used for large heat pump systems."

According to our data (though what we have is not enough for wide generalization), about 80% of supportive heating air source heat pumps were used with electric heating primary heaters. With consideration of most constraints and possibilities that might have an influence, we tried to evaluate efficiency of air source heat pumps. The comparison was studied between a house with direct electric heating as the sole heat supplier and the same house type except with an air source heat pump as the supportive heater. In fact, getting the same houses for comparison is quite difficult.Therefore, filtering with priorities on what matters most by consumption and using percentage of change in consumption from the average daily non heated season to average daily heated season is assumed as a solution.

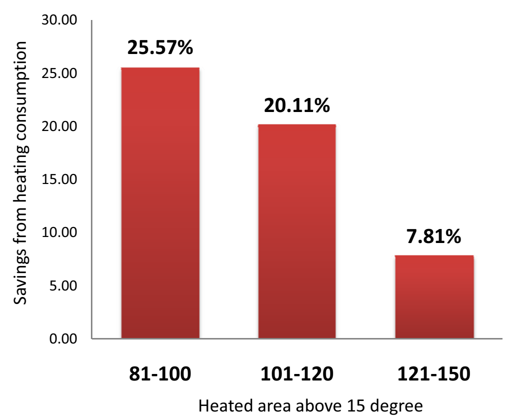


Figure 3.23: Percentage reduction of heat energy needed by using DE heaters with ASHPs than DE alone.

According to our assessment the following two conclusions were drawn

1. In comparison with direct electric heaters, using air source heat pumps as supportive heaters might decrease heating consumption by 7.8%-25.6%

2. Air source heat pumps suit best for a smaller heated area.

To see daily load structure in the heated and non heated season for a 101-120 sqm heated area from which the percentage is calculated, the graph in Figure 3.24 is drawn.

3.3 Energy saving lamps

According to 2006 report from Adato Energia, excluding consumption for heating, lighting accounts for about 22% of per-household electric consumption. In Finland, mainly four types of electric lamps are used for lighting purposes. Before giving

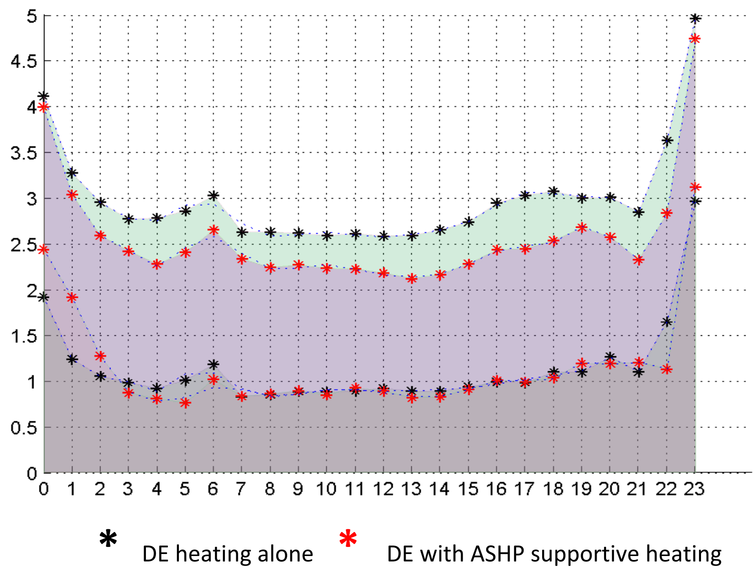


Figure 3.24: The daily load structure in heated and non heated season for direct electric heated households with and without supportive ASHPs.

the general statistical summarization of lamps let us define each of them in brief. At least depending on the most prominent lamps in Finland we can have two main classifications.

1. *Incandescent light bulbs*
   Incandescence is the process by which heated solids emit light in accordance with their temperature. The glowing filament (mostly tungsten) due to its resistive power gives light much similar to daylight. To prevent oxidation of the highly heated filament they are enclosed inside glass bulbs. The two most known incandescent bulbs are:

   a. *Conventional incandescent bulbs*
      These bulbs convert approximately 90% of total input power in to heat with only 10% of light. In spite of their cheap price and daylight seeming nature, these bulbs are highly inefficient and with short life span compared to compact fluorescent lamps. As a result, the European Commission has decided to ban them out by September 2012.

   b. *Halogen lamp*
      This incandescent bulb is intended to restore evaporated tungsten through a halogen cycle where significant decrease of light output and lifetime of the bulb in general is improved. In halogen lamps the filament is sealed in a compact transparent envelope filled with halogen gas. Their very high operating temperature and danger of explosion makes them hazardous to safety. On the other hand, their higher efficacy, color temperature and some times twice as much life span compared to other incandescent bulbs

makes them advantageous. According to our survey in the summer of 2009, these lamps account for about 15% of total lamps in a household studied.

2. *Fluorescent lamps*
   Fluorescence is the emission of visible light by a substance that has absorbed light of differing, usually invisible, wavelength. As the name suggests the involvement of heat in the process is not as defining as with incandescent bulbs. The process simply is that the potential difference between two electrodes at the two ends of fluorescent lamps initiates discharge of electrons. The discharge process evaporate mercury inside the tube, and when the accelerating electrons and charged atoms collide with gaseous mercury atom electrons of mercury will be excited to a higher energy level. The return of excited mercury electrons to their energy level emits light photons in UV range. The job of changing the UV to visible light is accomplished by phosphorous powder coating inside the glass tube. The regular fluorescent tubes account for about 15% of total lamp numbers in Finnish households. Compact Fluorescent lamps, which are essentially developed and shaped to replace incandescent bulbs, are expected to be the dominant ones in the near future. As of July, 2009 they account for above 20% of total lamp numbers in Finnish households.

   Fluorescent lamps in general have the following advantages:

   1. Compared to incandescent bulbs they use less power and also they are 4 to 6 times more efficient
   2. The average rated life of a CFL is between 8 and 15 times that of incandescent bulbs.

   The disadvantages of Fluorescent lamps might be summarized as follows:

   1. Most CFLs contain 3-5mg of mercury per bulb. Unsafe disposal of the lamps might result in air and water pollution
   2. The presence of a ballast, which stabilizes current through the lamp, will increase the initial cost of these lamps. In addition, there might be a humming or buzzing noise
   3. For an outdoor cold environment application, efficiency decreases drastically or sometimes it may not work at all
   4. Flicker and difficult of dimming
   5. In larger scale evaluation these lamps may create power quality and radio interference problems.

According to the survey conducted from June to July 2009 on 3830 households from Vantaa, Kajaani and the Savo area, the following statistical information is provided on lighting bulb distributions. Lamps distribution for indoor lighting is shown in

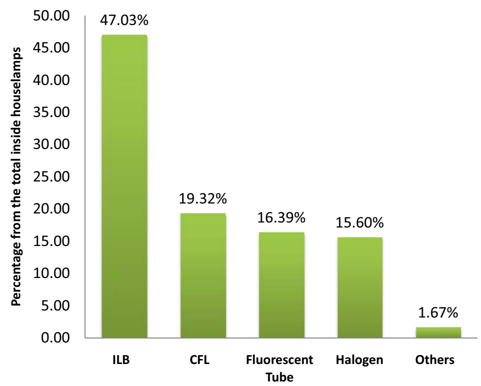


Figure 3.25: Indoor lamps distribution of a Finnish household.

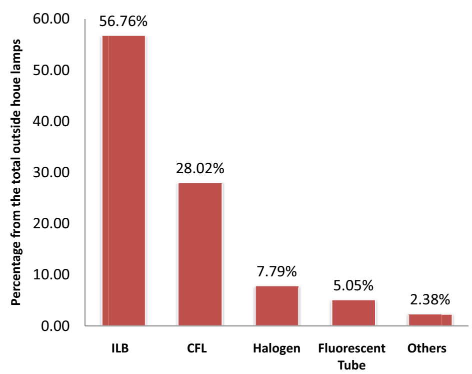


Figure 3.26: Outdoor lamps distribution of a Finnish household.

Figure 3.25. Lamps distribution for outside household application for an average Finnish house is shown in Figure 3.26.

Based on our database, in the average Finnish household, 62.86% of the total lamps are incandescent bulbs, 35.4% are fluorescent lamps and 1.74% other lamp types. Besides the statistical survey, we have one year of hourly measured consumption data of households from three different companies. The idea of this data analysis on lighting can be summarized in two points.

1. Efficiency evaluation of energy saving lamps in comparison to Incandescent bulbs

2. Study the effect of interaction of lighting types with primary heating types.

The linear regression in Figure 3.27 explain the trend that power consumption follows with the number of ILBs and Energy saving lamps in the house. It should be noted that the total number of lamps in a household is kept between 16 and 25, in addition only households of similar electronic equipment are considered in the analysis. One of the most important considerations are only those houses with primary heating of district heating are used in the analysis. Replacing every ILB by energy saving lamps might result from 13.62% to 17.06% of total household electric

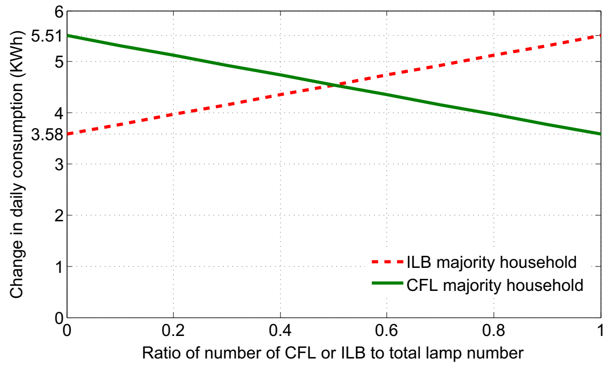


Figure 3.27: Correlation of number of lamps and electric power consumption for households with district heating system.

power consumption other than heating. Average day hourly power consumption of ILB majority households and their respective CFL majority households where their primary heating system is either district heating or oil heating is plotted in Figure 3.28.

Another observation from the data analysis shows that the expected savings of CFLs in the case of direct electric heated households was marginalized by possibly the heating effect of ILBs. This was observed when households of otherwise identical profile except for one with majority CFLs lighting and the other with majority ILBs were compared. The bottom line is that there is significant possibility of downsized savings from energy saving lamps in the case of direct electric heated households.

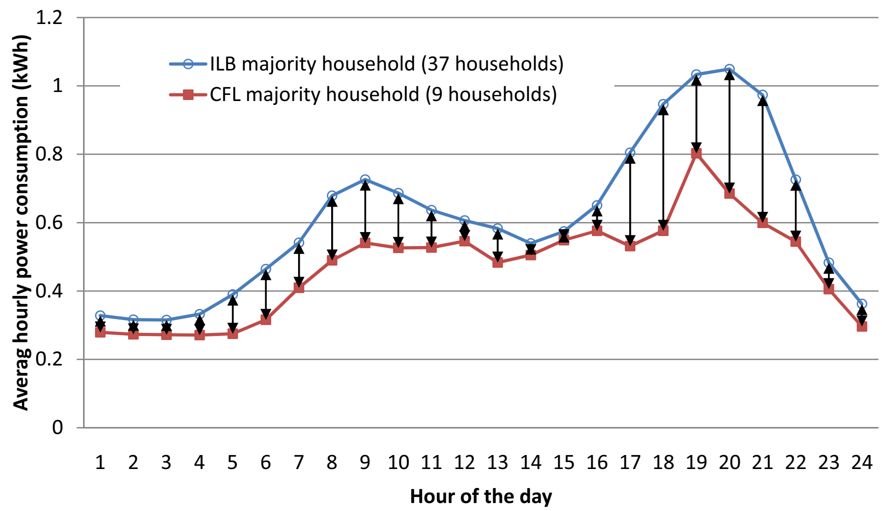
3.4 Ventilation systems

3.4.1 Common types of ventilation systems

1. *Natural ventilation without range hood*
   This ventilation system uses any opening naturally existing in the house. Doors, windows and chimneys might be used for exchange of stale air and fresh outside air driven by temperature and pressure difference. For a cold environment and insulated houses, however this type of ventilation is not practical. No electric power consumption in relation to ventilation.

2. *Natural ventilation with range hood*
   Range hoods usually incorporate an electric fan which extracts stale air from kitchen area. According to our survey about 47% of households use natural ventilation with a range hood. There are two problems here, firistly the unavailability of enough fresh air and, secondly heat loss with heated stale air.

3. *Mechanical exhaust ventilation*
   This is a system with only an exhaust fan which is located centrally connected



	Average daily consumption (KWh)
ILB majority households	14.75
CFL majority households	11.28

Figure 3.28: Households with district heating or oil primary heating system.

Observations from Figure 3.28:

1. Households of majority ILBs consume more than those with majority CFL households all the time

2. The variation in consumption gets significantly higher for hours of the day where lighting is used much.

Figure 3.29: Air flow with natural ventilation without range hood system.

to ducts sucking stale air from rooms with high probability of contaminated air, like the bathroom and kitchen. The depressurized building by this system takes in fresh air through leaks and intentional passive vents.

4. *Mechanical exhaust ventilation with exhaust heat pump*
The energy needed for domestic hot water is about 500 W and the exhaust air

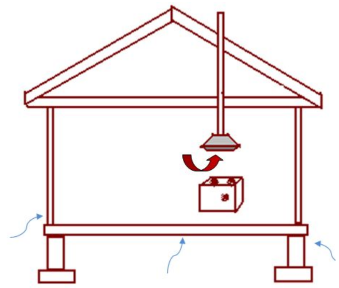


Figure 3.30: Air flow with natural ventilation with range hood system.

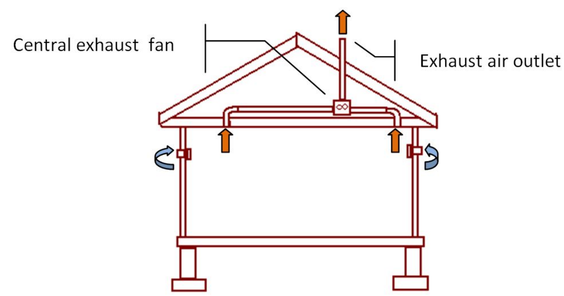


Figure 3.31: Air flow with mechanical exhaust ventilation.

energy content is three to four times more. [11] There are different mechanisms of recovering heat from exhaust air to make it available for reuse, and a heat pump is one.

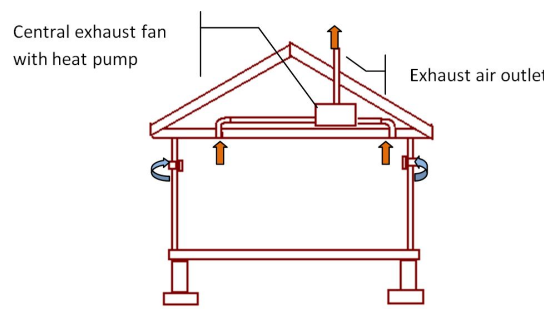


Figure 3.32: Air flow with mechanical exhaust ventilation with exhaust heat pump.

5. *Mechanical supply and exhaust ventilation*
   It is also called balanced ventilation system. These systems, if they are installed properly, introduce fresh air and exhaust polluted one with equal rate and no pressurization or depressurization involved. Due to their two duct and fan system these ventilation systems have expensive installation and operating cost.

6. *Mechanical supply and exhaust ventilation with heat recovery*
   Normally ventilation systems with heat recovery require more powerful fans

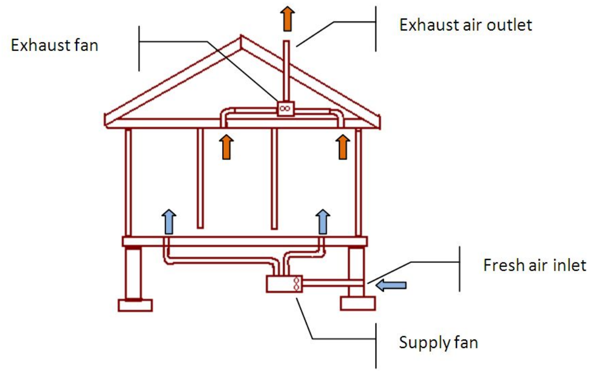


Figure 3.33: Air flow with mechanical supply and exhaust ventilation.

that use more energy to overcome the air resistance of the heat exchanger.

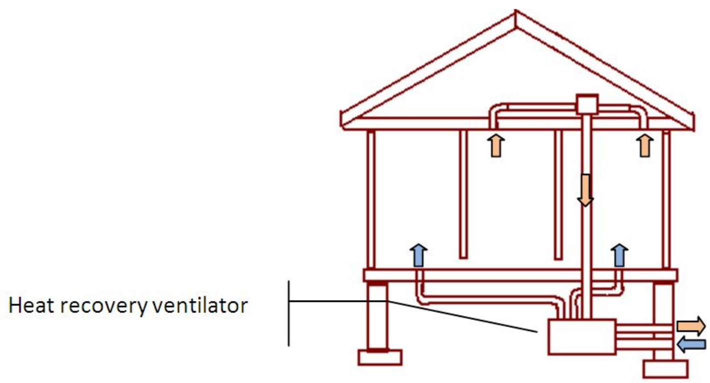


Figure 3.34: Air flow with mechanical supply and exhaust ventilation with heat recovery.

Among 3551 households in our database from Kajaani, Savo and Vantaa areas, the percentage of ventilation systems grouped under house year of construction is plotted in Figure 3.35. To gain a clear picture of the ventilation distribution, the household numbers in our database grouped under year of construction are given in Table 3.6.

Of the homes built after 2000 above 65% use a mechanical supply and exhaust ventilation with heat recovery. This might be due to the Finnish national building code (D2 2003), which requires at least 30% heat recovery from the exhaust air.

3.4.2 Effects of heat recovery systems

For well-insulated houses and efficient ventilation systems with heat recovery, ventilation systems will help primary heaters and the overall effect will be lower heating consumption. According to a study in Germany by T. Maier et al [11], the mechanical ventilation systems with a function of heat recovery showed lower heat

Table 3.6: Number of households in database grouped under building construction year.

Year of construction	No. of households in database
1950 or earlier	142
1950-1959	219
1960-1969	302
1970-1979	913
1980-1989	891
1990-1999	418
2000 or later	666

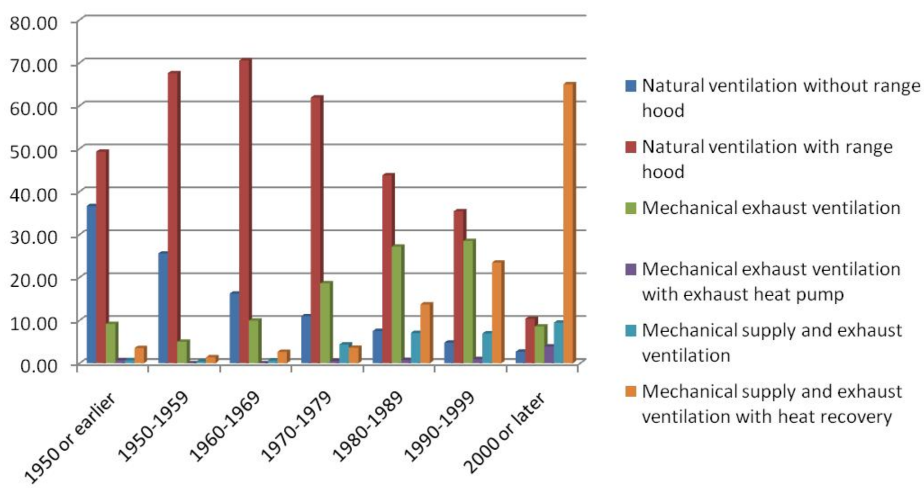


Figure 3.35: Ventilation types in each building construction year group.

consumption by about 10-30% than the systems with the mechanical ventilation with single ventilators and window ventilation.

The purpose of this analysis mainly is to evaluate the nature of ventilation systems from a power consumption perspective and, more importantly, in combination with primary heaters. Based on available data in our database, we calculated savings of ventilation systems with heat recovery from overall consumption. In the mean time, although thermal comfort of people should be considered in efficiency analysis, we have to state clearly that this time only power savings are considered. After grouping households according to their heated area over 15 degree and further grouping to mechanical supply and exhaust ventilation with and without heat recovery, comparison of the average power consumption for the time between January to February is done. The heated areas considered are 81-100 m2, 101-120m2 and 121-150m2. Therefore we have twelve groups of which, after refinement from our database, the minimum number of household in a group is 6. Furthermore, all households in this analysis are with primary heaters of direct electric heating or electric storage heating.

The total power savings of households with mechanical supply and exhaust ventilation with heat recovery compared to those with mechanical supply and exhaust ventilation is plotted in Figure 3.36.

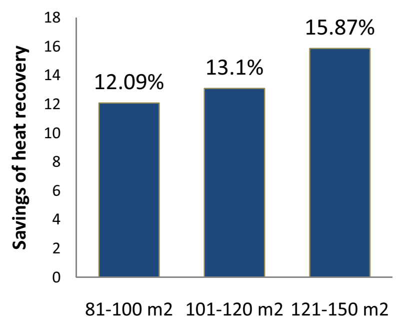


Figure 3.36: Savings from heat recovery incorporated ventilation systems.

The 90% confidence interval where the highest possible interval saving and the mean value is given in Table 3.7. On average, 13.6% of total power saving can be achieved

Table 3.7: 90% confidence maximum saving potential.

Heated area(sqm)	Mean saving	90% confidence highest interval saving
81-100	12.08%	37.85%
101-120	13.09%	26.94%
121-150	15.86%	34.87%

by using mechanical supply and exhaust ventilation with heat recovery systems compared to the total household consumption of mechanical supply and exhaust ventilation. This might be also an indication of the level of household insulation and efficiency of ventilation heat recovery systems.The daily average load curve of households of heated area 101-120 m2 for the analysis stated above is shown in Figure 3.37.

Two observations from the curve in Figure 3.37 which reinforces the calculation method are:

1 Households in the analysis use similar electric power purchasing scheme

2 The fact that an almost uniform consumption gap exists on the 24 hour time implies the at most heating and ventilation effect consideration in the analysis.

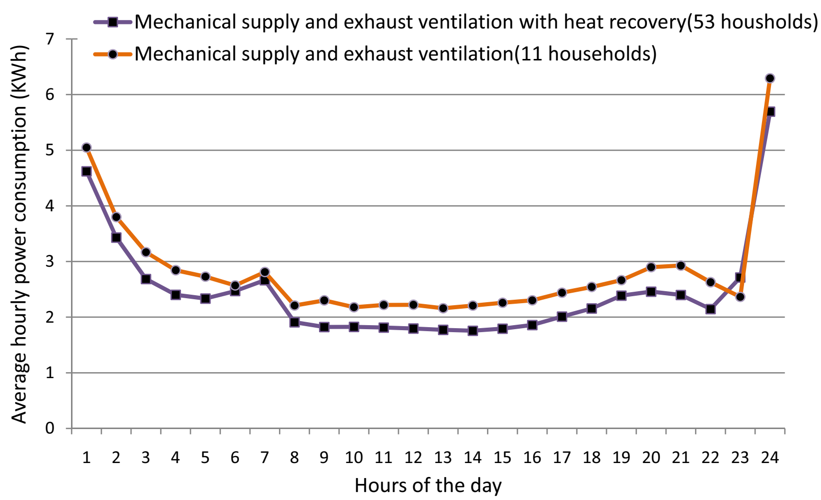


Figure 3.37: Average 24 hours consumption comparison between identical groups but one with heat recovery.

3.5 Electric storage heaters and direct electric heaters

Storage heaters work with the same principle as electric resistor heaters except that the heat is stored at a specific time and delivered throughout the day in a controlled manner. They are specially designed to take advantage of off-peak low price night time electricity. The retained heat, mostly inside bricks, will be released either radiatively from the case or by convection through bricks. In Finland, mostly water storage tanks are used instead of bricks and hot water circulating pipes deliver the heat. The main drawback of this heater type is its less controlled heat release, loss of stored heat and its heavy weight.

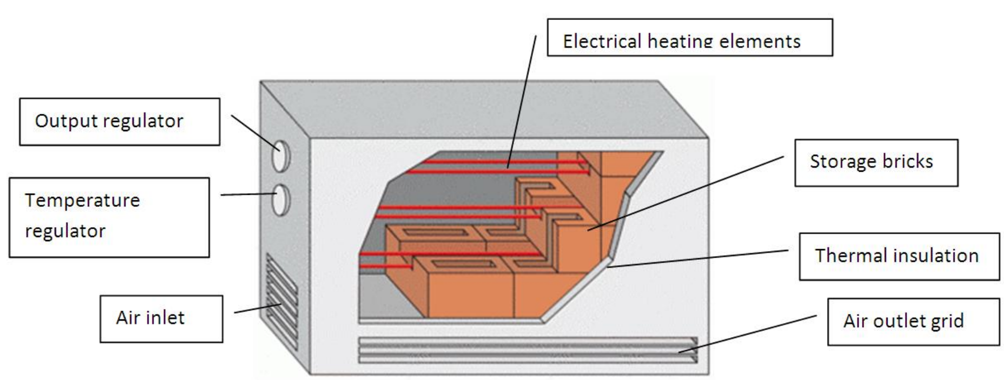


Figure 3.38: Air blowing storage heater.

Currently these heaters are designed with strong insulation and lot of intelligent control systems. The four types of storage heater control:

1. Manual control setting of core thermostat

2. Control of charge time using outside night temperature
3. Thermostatic control to a room temperature set point during charge period
4. Programmed control to optimize internal conditions at minimal cost of supply.

The distribution of storage heaters is getting higher in households built after 2000. The number of households from Vantaa, Savo and Kajaani with electric storage primary heaters is plotted grouped under the year of building construction.

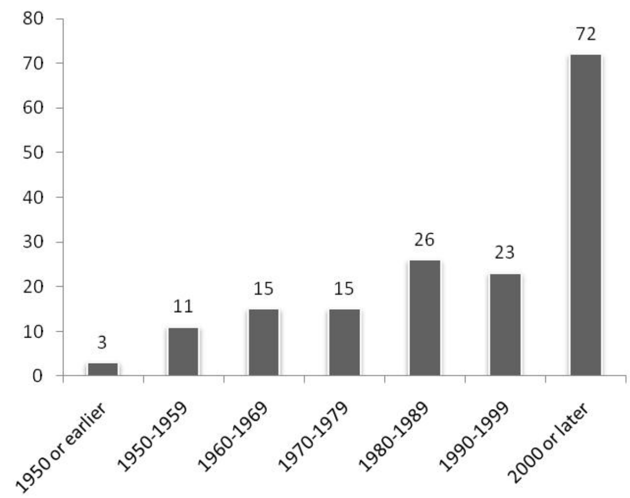


Figure 3.39: Storage heaters inside buildings of various construction years.

Almost all primary storage heaters are equipped with a supportive heating system. Also, the percentage of supportive heaters for electric storage primary heaters is plotted in the figure below.

As mentioned earlier, the main target of these heaters is lowering the cost of electric energy by tapping into off-peak low price electric energy sales. With this in mind, we plotted average winter day consumptions for households in the Kajaani and Savo areas to check how high the consumption peaks and how much consumption variation exists with continuous direct electric heaters. In the process, ventilation and wood consumption effects are minimized by grouping households of the same situation.

All households in the above groupings use wood heating as a supportive heating where their wood consumption is limited to be in the same range. The consumption of households with electric storage heaters is higher by about 8% than direct electric heated households. Households in the Kajaani area having direct electric heating as primary heater consumed energy with the same trend as electric storage households. This implies that there are other ways of utilizing night time cheap electricity price. In the Savo area, strangely, the cheap electricity price time coincides with normal household peak consumption hours.

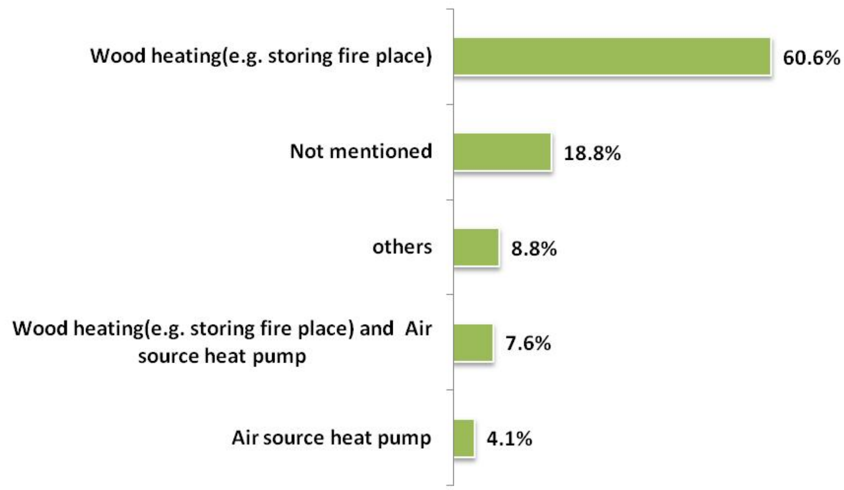
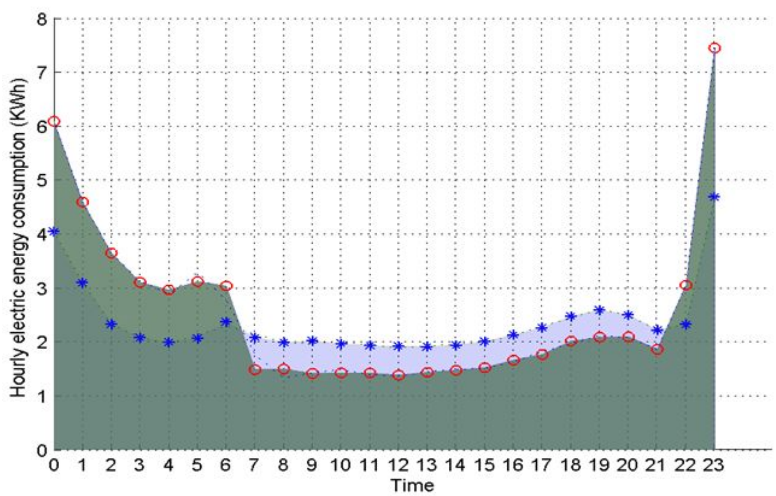


Figure 3.40: Supportive heaters associated with electric storage primary heaters.



Kajaani 101-120 sqm	No. of households	Jan-Feb avg daily consum. (kWh)
o Electric Storage	14	61.5
* Direct electric	23	56.9

Figure 3.41: Households from Kaajani grouped under direct electric heating and electric storage heating.

3.6 Garage and storage heating

These days, people use their garage for more than solely car parking purposes. Garages might be used as extended living spaces specifically for writing, personal workshop and hobby centers. In this case, continual heating might be needed throughout a chilling winter. Also, even for the case of car parking where extreme winter is experienced, heating is needed at least just before driving out every morning. On the other hand, garages are obviously less insulated than living spaces and sometimes open door garages might be used. Having said that; green garages are

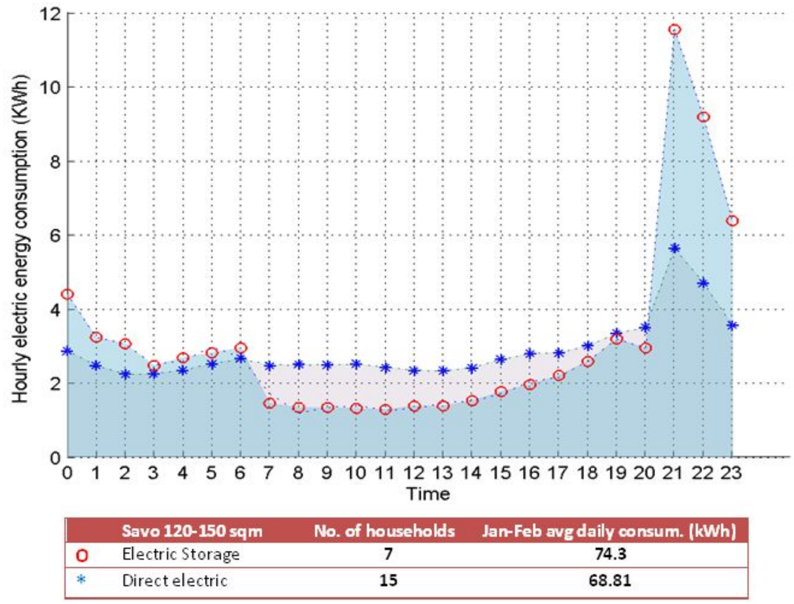


Figure 3.42: Households from Savo grouped under direct electric heating and electric storage heating.

needed so that significant amount of energy leakage to be prevented. According to our survey data from the Kajaani, Savo and Vantaa areas warm garages are observed as grouped below based on year of construction of houses.

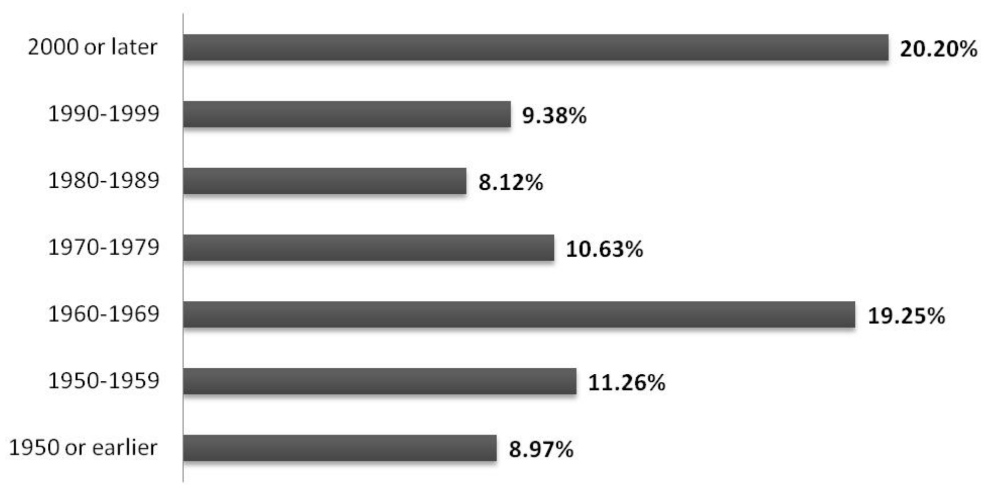


Figure 3.43: Percentage of households grouped under building construction year owning a heated garage .

Compared to the ventilation and overall heating system garage heating can be easily implemented in a house through renovation. This may be the reason why higher percentages of warm garage owners observed in houses constructed in the 1960's than the 1980's and 1990's. Overall, 12.3 % of households own either a warm garage or other storage areas.

The next thing we do is trying to observe if there is any significant heating consumption change due to presence of warm garage or storage areas. Households with an over 15 degree centigrade heated area of 120-150 sqm were grouped into two. The grouping was done by matching everything except for one group with the warm garage and the other with the cold garage.

Table 3.8: Power consumptions of identical households with difference in presence of warm garage.

	No of households		KWh
Warm Garage	7	Winter day average	87.62
		Summer day average	28.48
Cold Garage	5	Winter day average	78.7
		Summer day average	33.36

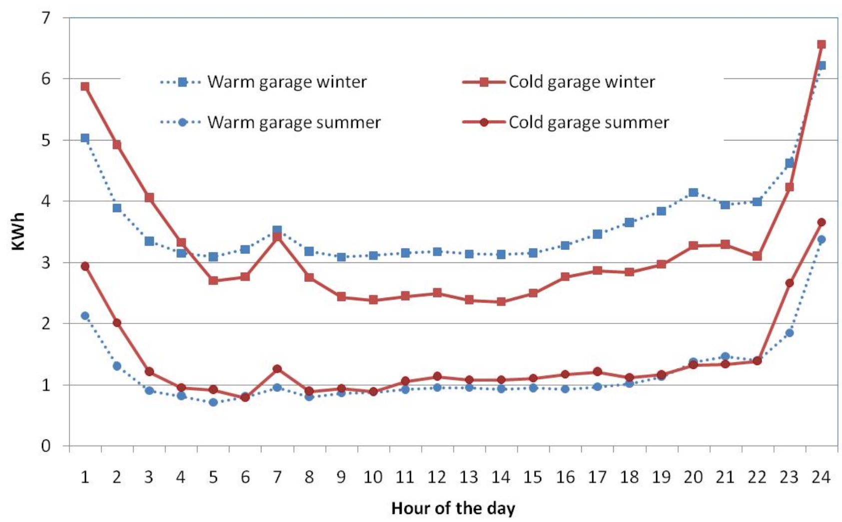


Figure 3.44: Comparison of heated and unheated garage average day consumption comparison.

From the above groupings, the percentage of garage heating consumption from the total heating consumption is estimated to be 23.3%. In other words, households with warm garage consume 30.4% higher heating consumption than those households with cold garage. To maximize efficiency in garage heating spot heaters of fast response can be used. Infrared heaters are among these heaters which can be used only just before garage use and have quicker heating ability. Insulating the area as much as possible is also another enhancement. Open door garages should consider using air curtains.

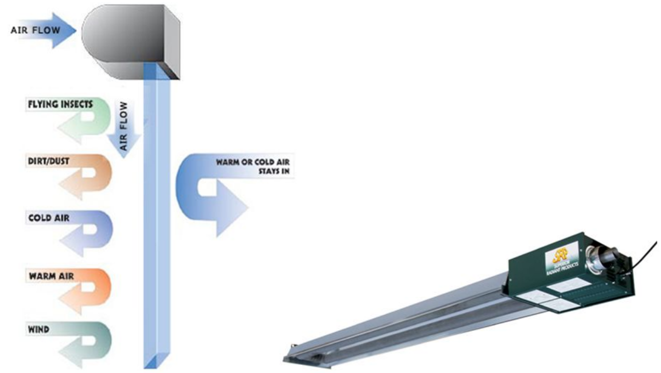


Figure 3.45: Air curtain(left), Infrared heater(right).

4 Saving potentials and fundamental factors

4.1 Evaluation of standby energy of households

The widely accepted definition of standby consumption is that it is the power consumption of appliances while not operating their primary function or they are switched off. Appliances with a remote control, external power supply, continuous display, or a soft-touch keypad will have standby energy use. The three common states of electrical appliances besides the primary function operating state are active state, passive state and OFF state.

1. Active standby mode: is a mode where the appliance is ON but not operating its main function. This applies mostly for DVD, VCR or CD players where they might be turned ON but not playing or recording.

2. Passive standby mode: this mode implies devices not charged but waiting to be turned on probably with remote control. It is also termed as deep sleep mode.

3. OFF mode: This is the lowest possible power state of equipment where they are plugged in but switched off by switch or button located on the device.

There are several standby modes in addition to the above three states specific to the individual appliance. For instance, a typical microwave oven consumes 3.08W in ready, door closed state and 25.79W in ready, door open state. [28] The fact that standby power consumption could happen in the above modes show how the variation from country to country could happen. Actually, in a single country standby consumption may vary from season to season or house to house because of variation in the states of appliances. Although the standby consumption of a single appliance is not much, the fact that they draw power continuously (24/7) and the numbers of these appliances are significant, making the problem necessarily to be addressed. According to the 2020 EU plan, the standby electricity consumption is expected to decrease by 73%. This is possible if a reduction rate of 50 TWh per annum is achieved, which is equivalent to Denmark's entire annual electricity consumption. Besides the alluring standby consumption of emerging electronic technologies, the current situation is not good in many countries. After studying various researches on this issue and collecting data from appliances' standby consumption measurements from companies, we assessed the situation in Finland. Mainly the analysis method is based on a study titled 'Quantification of residential standby power consumption in Australia'.[16] Top standby consuming appliances with their consumption and probabilities of operating states is given in Table 4.1.

Table 4.1: Top standby consuming appliances with their consumption and probabilities of operating states.

		Power consum.(W)			State probability			
Appliance	Penetration rate (%)	Act.	Pass.	Off	Act.	Pass.	Off	Standby(W)
Dishwasher	71.70*	1.5	0	0	0.975	0	0	1.46
Washing Machine	91.80*	2.6	0	0.4	0.65	0	0.325	1.82
Electric stove	89.45*	0	0	0.3	0	0	0.99	0.297
Desktop computer	51.38*	53.6	20.2	3.2	0.35	0.035	0.49	21.035
CRT monitor	18.07*	69.52	6.5	1.8	0.2	0.4	0.275	17.0
LCD monitor	33.32*	35	3.6	1.2	0.2	0.4	0.275	8.77
Computer portable	40.10*	30	13.9	1.6	0.35	0.035	0.49	11.77
CRTtv	60.89*	0	3.06	2.88	0.025	0.8	0.15	2.88
LCDtv	46.11*	0	3.3	0.2	0.025	0.8	0.15	2.67
Home theater	12.82*	0	1.2	21.1	0.025	0.8	0.15	4.3
ConsumerElec	56.40*	11.9	3.1	5.3	0.025	0.8	0.15	3.57
Microwave oven	90.00+	0	3.08	0.2	0	0.975	0	3.00
DVD	54.00+	5.7	1.2	0.3	0.025	0.8	0.15	1.15
Fixed line telephone	31.80+	0	2.25	2.01	0.425	0	0.5	1.01
*	Source: Questionnaire from 3830 households in 2009							
+	Source: Statistics Finland							

The estimation of operating times was done based on the study in Australia [16] and general assessment in the database where residents presence at home and switching OFF behaviors of people asked on the questionnaire. Also, the sum of all probability values of states is supposed to give 1, and, therefore, the remaining probability value after adding the three states is the normally operating state.

Now based on the information in the table we can make more general estimations. As some new phantom loads like digibox, gaming units and chargers are not included in this calculation, the result may only represent the 70%-80% of household total standby consumption. The total standby power consumption per household is on average 33.7W (the penetration rates are used in the calculation) and the yearly standby energy will be about 295.21 kWh per household. To calculate the national

standby consumption the following analytical approach is going to be implemented which take into consideration the level of penetration rate of each appliance in Finnish households.
Standby energy use in Finland

$$= 8.76 \times N \times \sum S_i \times W_i (kWhperyear) \tag{4.1}$$

Where N is the total household number in Finland, S_i is saturation rate (penetration rate) of appliance i and W_i is the appliance's standby consumption. According to Statistics Finland, as of 2006 the number of households was 2.4 million. Therefore, the national standby consumption is about 708.04 GWh per year. In 2006 the national electricity consumption of household was about 7.1TWh/a and, therefore, standby consumption accounts for 9.97% of household electricity consumption. The standby consumption level is comparable with other countries like Australia where it amounts to 11% of residential electricity use, 10% in Japan and 5% in the United States and other European countries.

Now for comparison study we will evaluate the standby power consumption based on hourly metered data and information gathered through a questionnaire from some of the 3830 households who were part of our study. According to many estimations of household power consumption trend, the time between 2 AM and 4 AM are the lowest consumption times provided that there is no special hour pricing from power companies. Refrigerators and freezers are 24 hour operating appliances with cyclic ON and OFF states. Any attempt to evaluate standby consumption from the daily load curve need to separate all time operating appliances and focus on lowest consumption hours of the day (the base load of the house). For one family detached house of particular heated areas, limited to 2 residents, having a ventilation system of natural ventilation with a range hood and primary heating of either district heating or oil heating, the daily load curves are plotted in Figures 4.1 and 4.2. The analysis is done based on hourly metered data of the lowest consumption season (June to July).

Table 4.2: Assumptions based on information database.

Appliance working in the time interval 2AM 3AM	Average number of appliances from database per household	Average power consumption (constant power drawing from mains Watts)
Refrigerator	1	33
Freezer	1	45
Lighting	1.5	90
Miscellaneous (eg. timers, table lamps.)	-	10

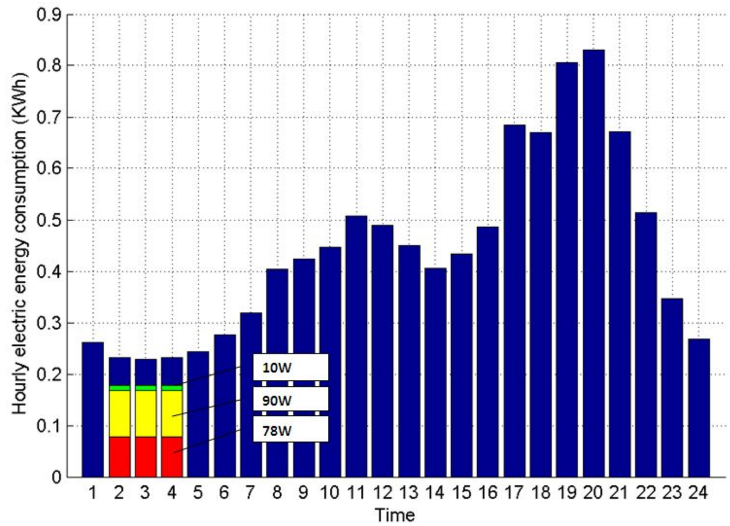


Figure 4.1: Average daily load curve of 17 households 101-120 heated area (53.08W average standby consumption).

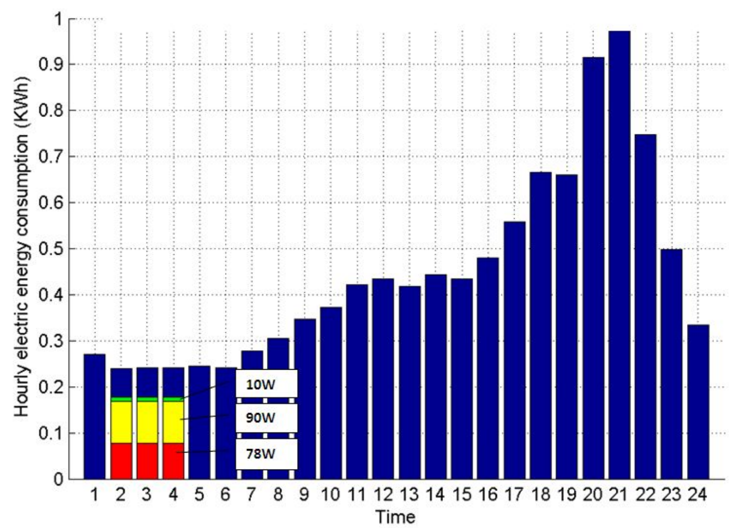


Figure 4.2: Average daily load curve of 8 households 120-150 heated area (62.819W average standby consumption).

	Calculated cooling device consumption
	Calculated lighting consumption
	Estimated miscellaneous consumption

The lighting consumption is calculated considering the average number of lamps outside the household from the database. It is important to state the two possibilities which keep each other in balance; one is the possibility of higher miscellaneous consumption and the other is the standby consumption at this time interval is expected to be less. The active and passive of standby consuming appliances mostly occur on hours where consumers are active.

For Natural ventilation with range hood systems, an extraction hood of about 150W is expected. According to reference [12], the hoods work on average for 300 hours and stay in standby mode for the remaining 8460 hours of the year. If we consider it as a constantly working appliance it will draw from 7- 10W. The rest of the power consumed in the stated interval is about 46.2W which is assumed to be standby consumption. This value is greater than the theoretical assumption 33.7W, where only about 70% of equipment might be represented. The bottom line is the average standby consumption of households according to our database is about 46.2 W $\pm$ 5W. The base load at the lowest consumption hour is an average 225.95W without the ventilation. The calculated standby power consumption from hourly measured data is 37% higher than the theoretical one. According to the information from the Selina project of the EU, the standby consumption of an average household in EU countries is about 30W and 169KWh per household per year. Another study from New Zealand estimates the standby consumption to be 58 W continuous.

4.2 Effect of Indoor temperature levels

The level of satisfaction with the thermal environment of a household can be termed as thermal comfort. ASHRAE 55-2004 and ISO 7730 view thermal comfort as 'specific combination of thermal conditions that will elicit the desired physiological state of comfort.' There is a gray area in elaborating the term for distinct portions of mental and physical comfort. Some researchers believe that the most part is the psychological state of mind and after some plus or minus from an optimum set point, physical comfort takes over. The level of comfort of people inside a building environment is so crucial that productivity, mood and lots of health issues are affected by it. Inside house environment, when wrongly set, might lead to Sick Building Syndrome.

Although level of comfort has a vast range of possible interpretations among different people, there is a consensus on basic necessities for healthy inside a home environment. According to the World Health Organization (WHO) recommendations, temperature for the main living area is 21^{o}C and for the rest of the home 18^{o}C. Lots of studies claim reduction of energy bill by 6-7% after setting the thermostat one degree lower. Moreover, studies show that one degree lowering could happen without disrupting the level of comfort noticeably. This analysis aims to evaluate and assess the potential of savings after lowering the thermostat setting by one degree.

First, let us show the distribution of thermostat set points among the 3534 households in our database, which are collected from Kajaani, Savo and Vantaa areas. In the questionnaire, in addition to the thermostat setting point, we also asked if they are willing to lower the already set thermostat.

For better visualization the bar graph in Figure 4.4 shows level of willingness in

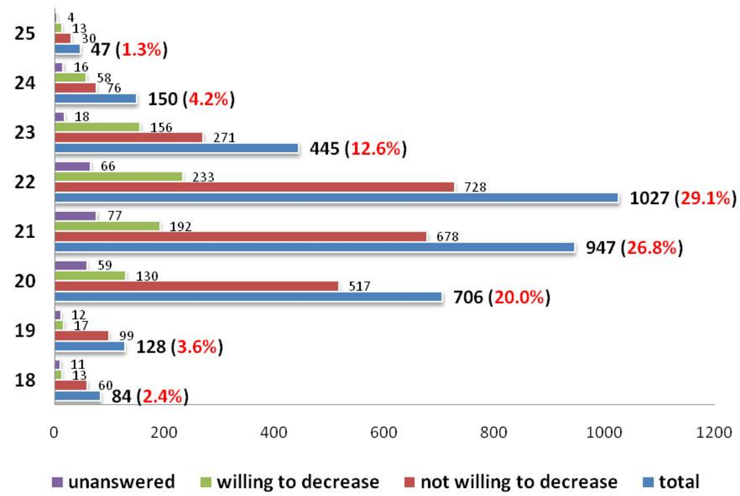


Figure 4.3: People willingness to reduce their temperature by one degree grouped under current inside room temperatures.

each temperature setting group. The levels of willingness, which is 23% among all

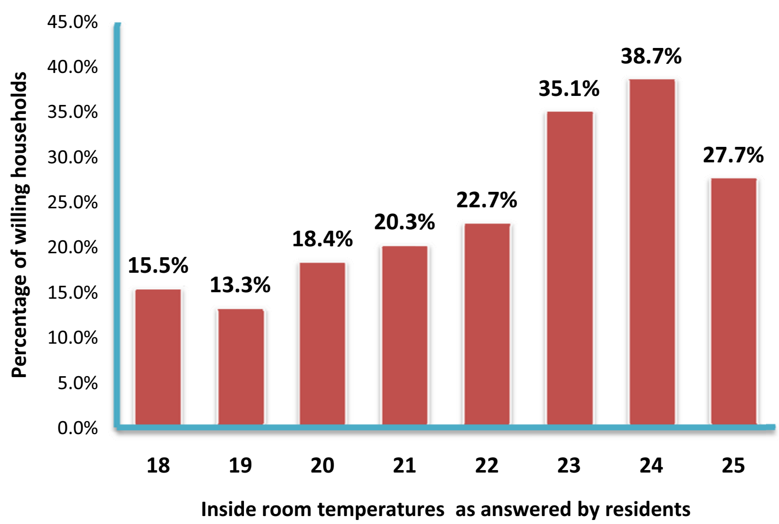


Figure 4.4: Percentages of households willing to reduce their room temperature by one degree grouped under current inside room temperatures.

households, indicate an awareness of the significant effect of lowering the thermostat set point on the monthly energy bill. Of course, it also indicates the will of people to change from their comfortable zone they are having now. If we consider households with thermostat setting from 22 degree to 25 degree separately, 27.5% of them are willing to lower their thermostat.

Households grouped under primary heating of other wood heating have a significant number of households with an inside temperature of 18 degree as well as a 25 degrees. This might be an indication of a loosely controlled heating system. The change in consumption from the average of typical summer days to typical winter days' is assumed to be heating consumption. After regression of the independent variable inside room temperature to the heating consumption, the result in Table 4.3 was achieved for various heated areas.

All households considered in this analysis are with direct electric primary heating and no other supportive heating unit. The assumption here that a rate of heating consumption increase for each degree inside the room temperature increment explains the value of one degree change on the total household consumption.

Table 4.3: Savings of setting back thermostat by 1 degree.

Heated area(sqm)	Savings from average winter day consumption through reduction of 1 degree inside room temperature.	Regression R Square
41-60	2.39%	0.013439
61-80	4.98%	0.183974
81-100	3.4%	0.044871
101-120	1.18%	0.003427

Actually, the variation in heating consumption from house to house is not expected to be explained entirely by the room temperature. Nevertheless, the savings mentioned in Table 4.3 are realistic and achievable. After normalizing with the heated area and calculating weighted average consumptions, an overall average saving of 3.43% of household consumption is observed for each degree lowering from inside room temperature during the winter heating season.

Average day consumption from January to February is plotted in Figure 4.5 for households with a heated area of 61-80 square meters. The households are further divided into groups in accordance with their reply concering the inside room temperature. All grouping criteria are the same as used for calculating the savings in the previous table.

Table 4.4 and Figure 4.5, however, can only be used for showing the trend of consumption variation for each hour, they cannot be used to calculate consumption variation due to temperature difference. To calculate the savings as stated above, we used the difference in consumption for each group by subtracting the average summer day consumption from the average winter day consumption. Through the process, hopefully, the effects of the difference in number of electronics and, also the number of residents, will be suppressed.

Table 4.4: Average winter day consumptions of households grouped based on their room temperature.

Room temperature in degree centigrade	Number of households in the group	Average daily consumption in kWh
18	5	36.91
19	1	47.61
20	14	48.38
21	14	53.16
22	15	58.23

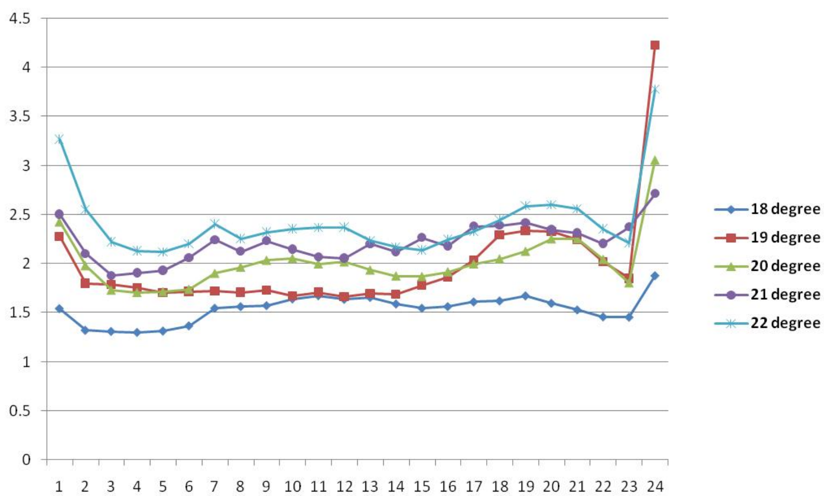


Figure 4.5: Average winter day 24 hour consumptions of households grouped based on their room temperature.

After creating awareness about savings by managing thermostat setting points, if the user is expected to remember and set it all the time, it will be impractical. The type of the thermostat itself is another issue. According to responses to question which ask the presence of automation for heating system, out of 3830 households from Kajaani, Savo and Vantaa area only 18.4% replied positive. With programmable thermostats the savings is enormous and with no need of follow ups.

4.3 Programmable thermostat savings

The average room temperature of Finnish household is about 21 ^oC according to our database. And among the households in our database only 18% of them use programmable thermostats. Now, we will evaluate the potential of savings due to night time temperature setbacks with programmable thermostats. We chose a benchmark temperature of 21 ^oC and setback temperature of 16.5 ^oC based on the recom-

Table 4.5: Programmable thermostat setpoint times and temperatures as recommended by Energy Star.

Setting	Time	Setpoint Temperature(Heat)	Setpoint Temperature (Cool)
Wake	6:00 a.m.	21^{o}C	25 ^{o}C
Day	8:00 a.m.	Setback at least 4.5^{o}C	Setup at least 4^{o}C
Evening	6:00 p.m.	21^{o}C	25 ^{o}C
Sleep	10:00 p.m.	Setback at least 4.5^{o}C	Setup at least 2^{o}C

mendation of Energy Star. To calculate the percentage saving of a programmable thermostat setback in comparison with non setback heating, a model house with this specification is selected as shown in Table 4.6. We used features of standard concrete block house built after 2000 as is specified in reference [18].

Table 4.6: Model house general specification.

Building volume	building m^3	466
Floor area	floor m^2	163
Heated area	m^2	142
Heating season	September May	
Effective thermal capacity	Wh/(mK)	40
Effective thermal capacity	kJ/(floor m K)	412

Table 4.7: Thermal resistances of the model house

	Area(m^2)	Structural U values, W/(mK)
External walls (130 m)	130	0.26
Ground floors sup-ported on ground 1) (153 m)	153	0.38
Roof slabs (153 m)	153	0.16
Windows (18,7 m)	18.7	1.33
Entrance doors (7.9 m)	7.9	1.40

There is optimum value for temperature setback where effective pickup assures energy savings. A very low temperature setback and step increment to the benchmark temperature might, however, end up with higher consumption. With regards to the setback temperature we will stick to the recommendation of Energy Star. But the time required for an effective ramp increment time should be calculated using the following formula.

$$t = \frac{C \triangle T}{P_{tot} - UA(T_{set} - T_{out})} [19] \tag{4.2}$$

After calculating some of the values based on the model house, we chose the recommended power of heater for a minimum temperature which is -28 ^{o}C in the Kajaani area for the year 2008/2009. The evaluated values are given in Table 4.8.

Table 4.8: Calculated specific values.

C (kWh/^{o}C)	18.64
$\triangle T$ (^{o}C)	4.5
P_{tot} (kW)	48
$U \times A$ (kW/^{o}C)	0.1523
T_{set} (^{o}C)	21

The time needed for the ramp increment depends on the outside temperature and the lower the outside temperature, the longer the time needed for pick-up. For various $\triangle T$, change between set-back and benchmark temperature, the pick-time is plotted in Figure 4.6.

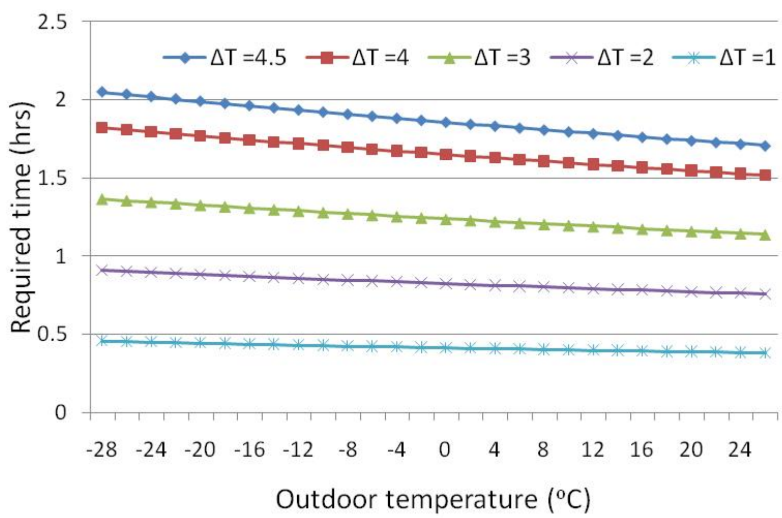


Figure 4.6: The pick-time required for various temperature changes between set-back and benchmark.

Considering the heating season to be September-May, the average outside temperature of the Kajaani area on 2008/2009 was 0.5 ^{o}C. We will make a calculation for the percentage of savings assuming this temperature as the constant outside temperature. For an outside temperature of 0.5 ^{o}C, the time required for the heater ramp to the set day time temperature is equal to 1 hour and 50 minutes. The heating degree

Table 4.9: Energystar recomended programmable thermostat setting.

4:10 am	Ramp starts
6:00 am	21 ^oC
8:00 am	Set back to 16.5 ^oC
4:10 pm	Ramp starts
6:00 pm	21 ^oC
10:00 pm	Set back to 16.5 ^oC

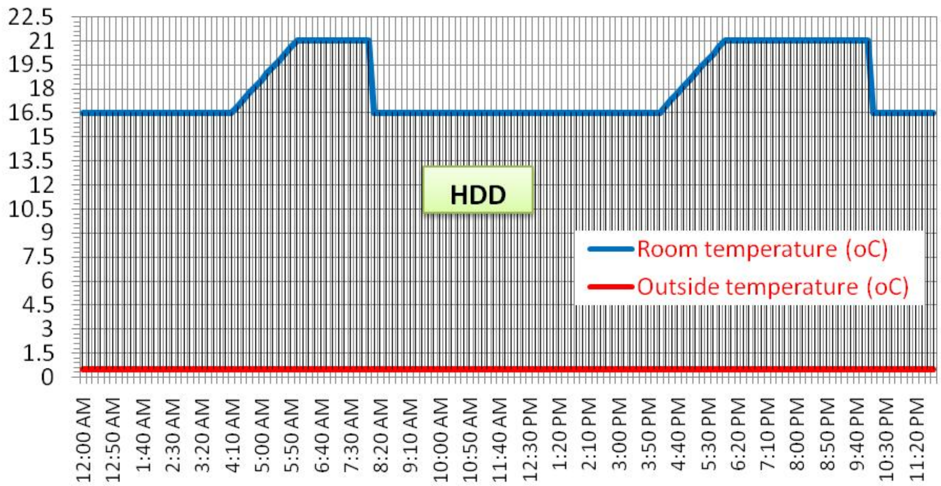


Figure 4.7: HDD for programmable thermostat.

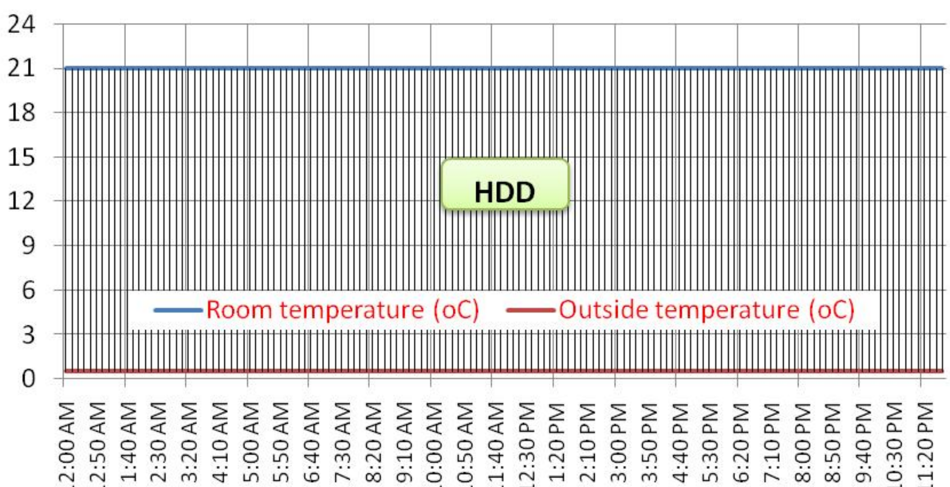


Figure 4.8: HDD for mechanical thermostat.

days of a representative day for the two groups of thermostat settings is calculated from the following daily profile plots.

The average room temperature for a room with a setback program of programmable thermostat is 18 ^oC. This implies for this representative day the heating degree day is 17.5. On other hand, the heating degree day for a constant thermostat setting room is 20.5. With the information at hand, the rate of heat loss of the model house can be calculated using the following formula:

$$Theamountofheatrequired(kWh) = HDD \times UA \times 24 \tag{4.3}$$

Where

HDD Heating Degree Days

UA overall loss coefficient (kW/^{o}C)

UA = 0.1523, for the model house. Therefore, the amount of heat required for the single day:

With thermostat setback = 64 kWh

With constant thermostat setting = 75 kWh

At average 14.7% saving from heating energy can be achieved by using programmable thermostat following the Energy Star recommended setting. More generally, the saving as a function of average outside daily temperature can be approximated by the following formula:

$$Saving(\%) = \frac{3}{21 - T_{out}} \times 100 \tag{4.4}$$

In fact, the saving is a function of ramp time t and outside temperature which looks like the graph in Figure 4.9.

The saving is enormous as the numbers tell. Also, it should be mentioned that the calculation is specifically done for the Kajaani area and house insulation as stated for model house. But neglecting the effect of ramp time t, we can assume that the percentage saving is valid for any house in the same temperature zone. One problem for thermostat setback timing is that when all electric heated households implement same program in the same area, the peak load will exceed the usual peak load hours. A study which focused on the situation in Quebec, Canada, where 70% of households are electrically heated assessed the effectiveness of the pick-up algorithm. [19] The algorithm shifts the power demand from the utility's peak period to an off-peak period.

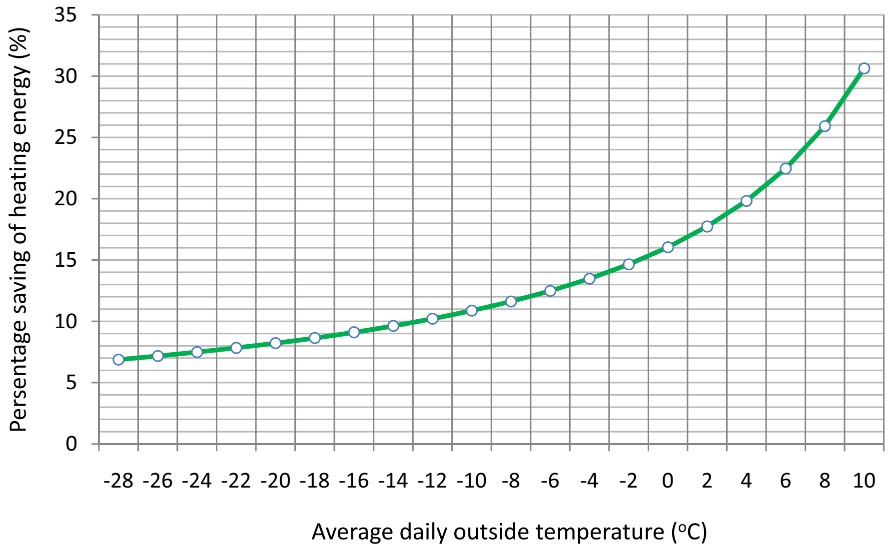


Figure 4.9: Outside temperature dependancy of programmable theromstat savings.

4.4 The waste heat effect

The heat replacement factor is the proportion of the energy used by the appliance that offsets energy that would otherwise be provided by the heating system. Lighting, the refrigerator, consumer electronics and standby loads are the main sources of waste heat. The idea of evaluating the heat replacement factor appeared after realization of an increase of heating power demand as energy saving appliances replace older devices. In some cases, the heat contribution of the appliance will be so significant that the saving will be offset by the additional demand from the primary heater. The situation becomes more relevant as we go to the northern cold environment. This analysis, based on hourly power consumption and survey data, traces the effect of waste heat on primarily direct electric heated Finnish households.

According to reference [25], the heat replacement factors of grouped appliances for dwellings in Britain is calculated as shown in Table 4.10. A heat replacement factor of 46.9% for a refrigerator implies the percentage of consumed energy by refrigerator which turned out to be additional heat for the house. But this does not mean that all waste energy from appliances ends up with effective heating in a household. Depending on the position of the appliance and way of heat delivery (might be conduction or radiation); the influence in the building heating system might be suppressed. The ability of thermostats to respond rapidly to changing ambient temperatures should also be taken under consideration. Analyzing hourly measured power consumption for evaluation of waste heat utilization is quite susceptible to misleading interpretation. Nevertheless by avoiding other factors, though not completely, we calculated the percentage of the contribution of waste heat from appliances to the household primary heating system. The appliances, which can have an spotted influence in

Table 4.10: Heat replacement factors of grouped appliances for dwellings in Britain
.

Domestic appliances	Heat replacement factor R
Lighting	60.00%
Refrigerators and freezers	46.90%
Cooking (electric)	49.40%
Cooking (gas)	49.40%
Wet (washing machines, etc)	2.30%
Consumer electronics	49.40%
Standby power	48.40%
Added heating (electric)	100.00%
Added heating (gas)	100.00%

the daily load curve, also with statistical information for analysis, are categorized: under the following groups

- Lighting
- Refrigerators and freezers
- Cooking
- Wet (washing machines, etc)
- Consumer electronics

To sort out heating effect of refrigerators among the total heating energy is quite difficult. Every household has a refrigerator and also refrigerators are 24/7 working appliances. But still we were trying to get the heat supply of consumer electronics, lighting and cooking appliances where their immediate effect can be traced back just after the probability of their working hours. The idea is that there are high probability times for operation of these devices and the thermostat responds to the heating effect immediately after an appliance turned on and, as the result depth can be seen in the consumption profile of direct electric primary heater. According to Table 4.11, between hour 7:00 am and 12:00 am, the spike following depths of heating consumption might implicate the waste heat effect of lighting, wet appliances, consumer electronics and cooking appliances.

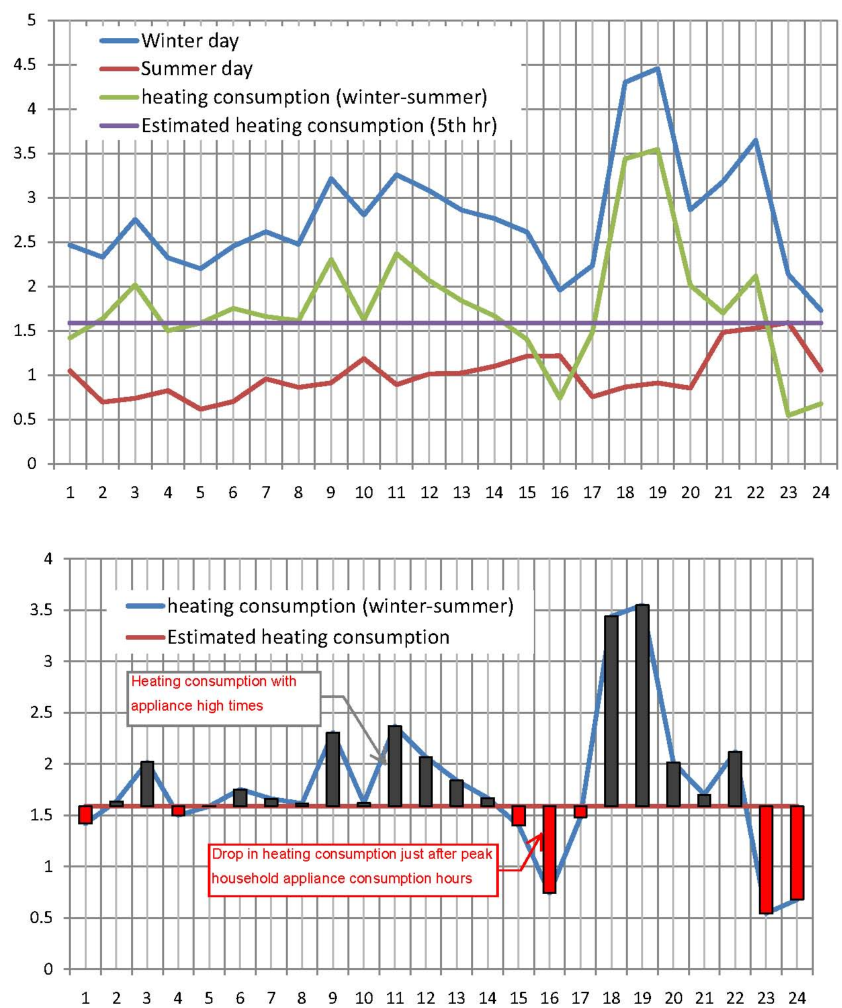
Among 10 households selected carefully and with the analysis method stated above, an estimated average of 7.14% of heating consumption is accounted for waste heat from appliances. The standard deviation of 0.052 has been noticed in the group.

Table 4.11: Hourly probability factors of appliances within 24 hour period.[23]

Appliances		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Stove and oven	we	0.20	0.20	0.40	0.40	1.78	2.59	3.19	3.83	3.70	4.13	4.29	4.15	3.89	4.46	5.79	8.76	10.0	10.3	9.24	8.15	5.82	2.79	1.51	0.36
	wd	0.37	0.05	0.00	0.00	0.00	0.17	1.72	2.65	4.37	5.94	6.97	7.86	7.92	7.15	6.39	5.89	6.78	7.41	7.32	7.23	6.93	4.09	2.30	1.02
Microwave oven	we	0.20	0.20	0.40	0.40	1.78	2.59	3.19	3.83	3.70	4.13	4.29	4.15	3.89	4.46	5.79	8.76	10.0	10.3	9.24	8.15	5.82	2.79	1.51	0.36
and Coffee maker	wd	0.37	0.05	0.00	0.00	0.00	0.17	1.72	2.65	4.37	5.94	6.97	7.86	7.92	7.15	6.39	5.89	6.78	7.41	7.32	7.23	6.93	4.09	2.30	1.02
Refrigerator and	we	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17
Freezers	wd	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17	4.17
Dishwasher	we	1.73	0.96	0.40	0.40	0.40	0.96	1.73	2.93	3.75	4.58	4.68	4.68	4.68	4.68	4.68	6.11	6.83	7.16	7.80	8.60	8.16	7.01	5.05	2.03
	wd	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.70	2.00	4.61	7.02	7.23	7.23	7.34	7.34	7.34	7.43	7.43	7.74	7.74	7.43	6.12	3.91	0.90
Clothes-washer	we	1.73	0.96	0.40	0.40	0.40	0.96	1.73	2.93	3.75	4.58	4.68	4.68	4.68	4.68	4.68	6.11	6.83	7.16	7.80	8.60	8.16	7.01	5.05	2.03
and Tumble dryer	wd	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.70	2.00	4.61	7.02	7.23	7.23	7.34	7.34	7.34	7.43	7.43	7.74	7.74	7.43	6.12	3.91	0.90
Televisions and	we	2.40	1.20	0.70	0.60	0.70	1.30	2.10	2.45	3.35	3.20	3.20	3.84	3.84	4.00	4.80	6.39	7.99	7.99	7.99	9.59	7.99	6.39	4.80	3.20
Video recorder	wd	3.40	1.94	0.87	0.77	0.87	0.97	0.97	1.46	2.43	3.40	3.88	4.85	4.85	5.93	6.13	6.80	6.80	6.80	7.77	8.25	6.80	5.34	4.85	3.88
Radio/player	we	2.40	1.20	0.70	0.60	0.70	1.30	2.10	2.45	3.35	3.20	3.20	3.84	3.84	4.00	4.80	6.39	7.99	7.99	7.99	9.59	7.99	6.39	4.80	3.20
	wd	3.40	1.94	0.87	0.77	0.87	0.97	0.97	1.46	2.43	3.40	3.88	4.85	4.85	5.93	6.13	6.80	6.80	6.80	7.77	8.25	6.80	5.34	4.85	3.88
Personal computer	we	2.40	1.20	0.70	0.60	0.70	1.30	2.10	2.45	3.35	3.20	3.20	3.84	3.84	4.00	4.80	6.39	7.99	7.99	7.99	9.59	7.99	6.39	4.80	3.20
and Printer	wd	3.40	1.94	0.87	0.77	0.87	0.97	0.97	1.46	2.43	3.40	3.88	4.85	4.85	5.93	6.13	6.80	6.80	6.80	7.77	8.25	6.80	5.34	4.85	3.88
Lighting	we	1.03	0.33	0.33	0.83	1.78	2.64	3.56	3.74	3.44	3.04	3.04	3.24	3.94	4.14	4.55	4.96	5.79	6.70	8.21	9.11	9.81	8.50	4.32	2.96
	wd	2.55	1.33	1.23	1.23	1.33	1.53	2.13	4.05	5.07	4.99	4.27	3.82	3.57	4.27	4.97	5.50	6.02	6.69	7.34	7.56	6.64	6.17	4.49	3.22
Other occasional	we	1.03	0.83	0.83	0.83	1.03	2.04	3.06	3.24	3.44	3.54	3.64	3.74	3.94	4.14	4.55	4.96	5.79	6.70	7.71	8.51	9.01	8.10	5.67	3.66
loads	wd	2.55	1.33	1.23	1.23	1.33	1.73	2.13	3.55	4.07	3.99	3.77	3.97	4.07	4.47	4.97	6.00	6.32	6.84	7.34	7.56	6.79	6.67	4.84	3.22

we = weekend day
wd = weekday

Figure 4.10: Estimation of effect of waste heat just after peak consumption hours.



4.5 Wood consumption

The European Union 2020 action plan demands Finland to increase the nation's share of renewable energy sources to 38% of total consumption. As of 2008, 27.2% of total energy consumption is from renewable energy sources of which above 77.7% is from wood fuels. The application of wood for space heating is quite significant in Finland. In farmhouses an average firewood consumption of 20 m^3 is estimated annually. The average rural household firewood consumption ranges from 3 to 4 m^3 yearly. [21]

The market share of space heating for 2005 (source: Tiitinen 2006) show 11.8% fuel from firewood.

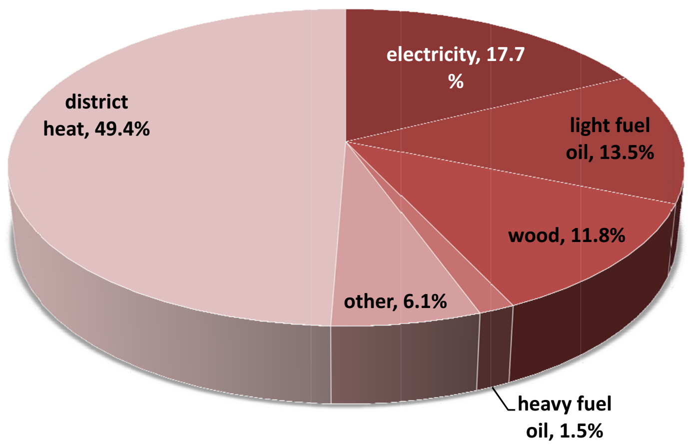


Figure 4.11: The market share of space heating for 2005 (source: Tiitinen 2006).

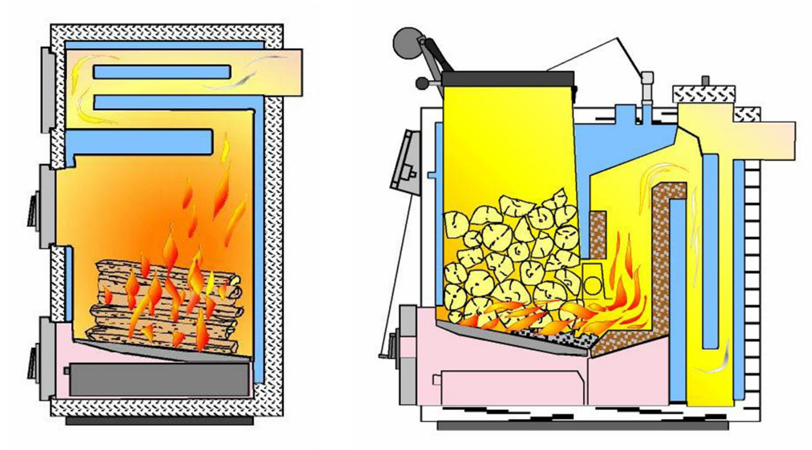
Leaving comparatively little ash, wood burns with little smoke and easy ignition. Although it requires a larger storage area and more labor in its preparation, it is still widely used as a heating fuel. Besides the open fireplaces nowadays there are efficient and safe wood burning heating systems available in the market.

The typical heating systems in Finland which use wood fuel are listed below.

Log boilers
These boilers consume split log wood up to half meter in length. They (especially over-fire boiler types) are usually connected to a water heat accumulator, approximately 1-5m^3 in size which enables it with only a few hours of combustion a longer heating time. Log boilers are mostly used as primary heaters in rural areas. The two most common log boilers in Finland are shown below.[21]

Heat retaining stoves
The basic principle of the heat retaining stove is that the massive (1000-3000

Figure 4.12: The principle of an overfire boiler (left), the principle of an underfire boiler (right)[21]



Kg) body of the stove store the heat supplied during 2-3 hour of very efficient combustion. The heat then transfers to the fireplace slowly which ultimately heats the household through convection and radiation. This most typical system in Finland is used as supportive to houses heated by electricity.

Figure 4.13: Heat retaining stoves (Tulikivi Oyj).

The other fireplaces common in Finnish summer cottages and recreational houses are normal open fires, baking ovens, pellet stoves and sauna stoves. In an attempt to effectively harness renewable wood fuel for household heating, redesign of stoves and life cycle emission analysis of fuel are the two important possibilities for further efficiency improvements. This study is, however, limited to data analysis by evaluating savings of supportive wood heating combined with various primary heaters.

Figure 4.14 shows the percentage of households with wood supportive heating in each primary heating group. In addition to fully wood heated households, every primary heating system is supported with wood heating. The trend in the graph of Figure 4.14 may also tell something about the level of reliability or comfort of the primary heater type.

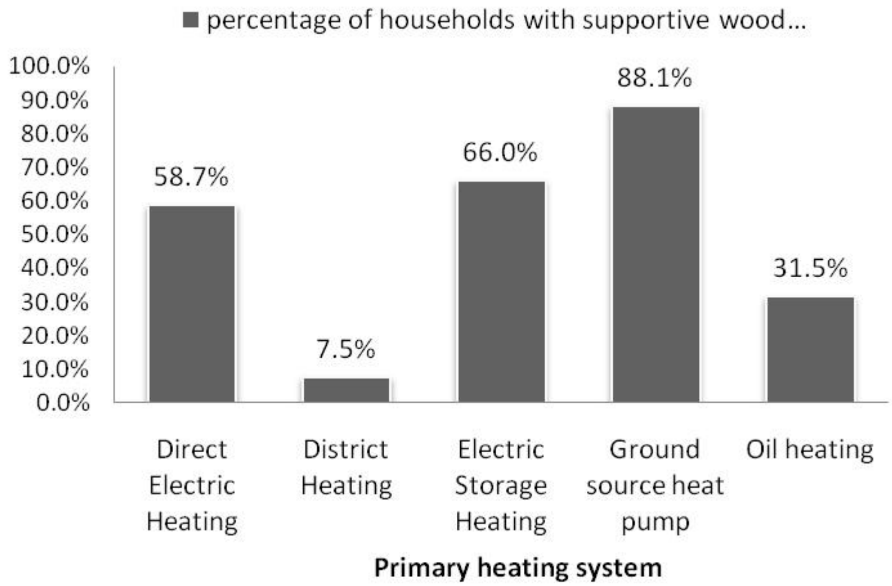


Figure 4.14: Percentage of households with wood supportive heating grouped with their primarey heater type.

In evaluation of the level of harmonies between primary heaters and supportive wood heating, we used households with direct electric heaters as the source of our main data is hourly measured power consumption. As wood fuel is considered to be emission free, the graph in Figure 4.15 illustrate the potential of electric power savings for switching from a fully direct electric heating situation to a fully wood heating situation.

The curve was drawn for those households of 101-120 m^2 heated area and natural ventilation with a range hood. Also, only working days consumption is considered to avoid other highly variable factors. Here also there is an assumption that the difference between summer-time daily consumption and winter-time daily consumption explain the mainly heating consumption of the house. With all possible errors, households of wood primary heating consume 58% less of total household consumption in the peak heating season compared to households with direct electric primary heating.

Moreover to evaluate the response in electric power consumption for each additional m^3 wood heating, we grouped households into four and the peak heating season daily power consumption is graphed in Figure 4.16.

The daily curves in Figure 4.16 illustrate the uniformity of variation of power con-

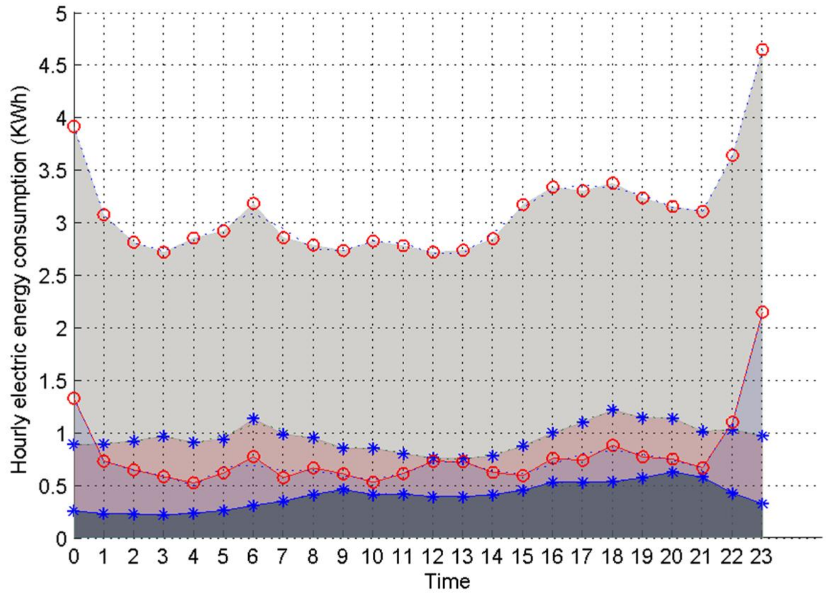


Figure 4.15: Average day consumption comparison of primarily wood and primarily direct electric heated houses.

		households	Average daily consumption (kWh)
Direct electric primary heater(winter)	O	10	70.37
Direct electric primary heater(summer)	O	10	16.93
Wood primary heating(winter)	*	19	21.94
Wood primary heating(summer)	*	19	9.27

sumption in each hour of the group during the day. The non uniform hours may imply the effect of short period operation of specific electrical appliance. In the above graph, a fairly uniformly operating system, which is mainly the heating system, affected the variation. That said, the average yearly wood consumption of each group was calculated from the database and, with the corresponding daily average power consumption, it is plotted in Figure 4.17.

The regression of wood consumption with daily average power consumption imply a reduction rate of 2.32 kWh in each day of winter-time consumption for each m^3 heating wood burning in a year.

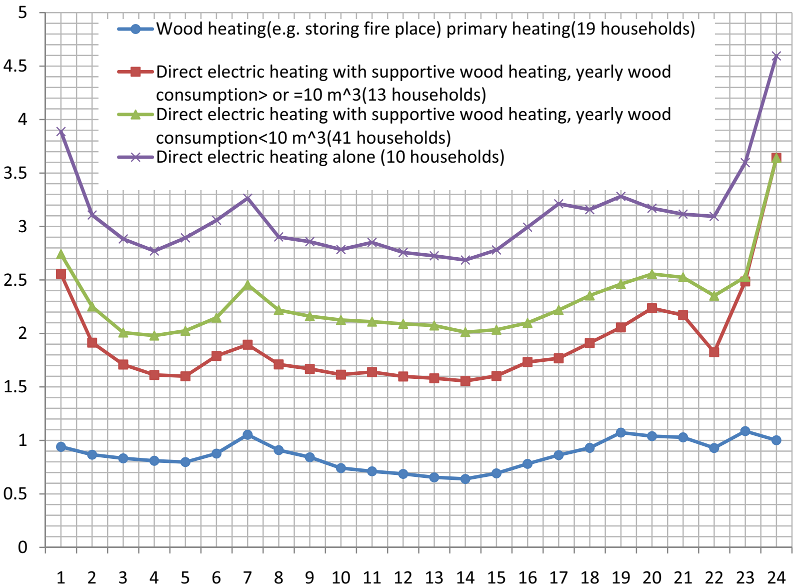


Figure 4.16: Average daily power consumption comparison of level of m3 consumptions of wood.

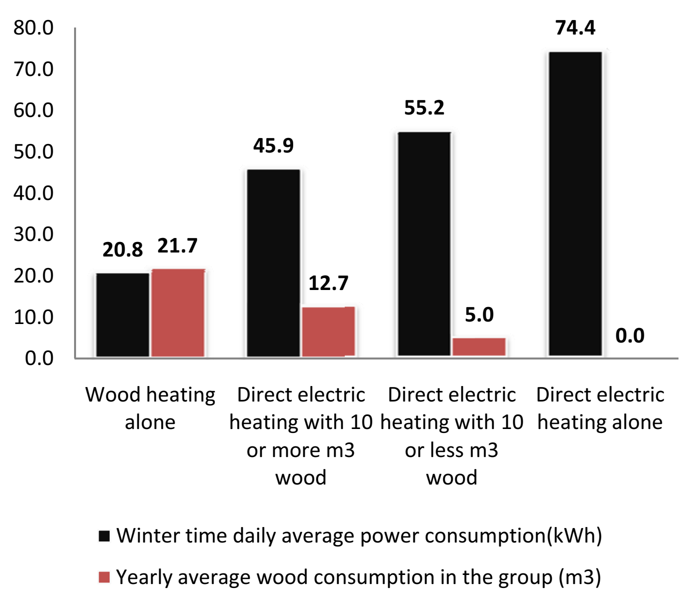


Figure 4.17: The average yearly wood consumption with the corresponding daily average power consumption.

5 Conclusions

This thesis analyzed both the efficiencies and potentials for making savings of various household electric end-uses. The analysis was done based on survey data and AMR metered hourly household power consumptions. Unlike previous studies, this thesis evaluated factors considering the combined effect of various end-uses. Through the process, factors have been extracted with their respective marginal errors. Table 5.1 summarizes the main results of the analysis.

Table 5.1: Summary of results.

End-use type	Action	Saving/Factor evaluated
GSHP	Replacing direct electric heating with GSHPs.	Saving of 27.45% to 47.0% of heating consumption with direct electric heating.
ASHP	Using ASHPs with direct electric heaters as supportive heating.	Reduction in heating consumption by 7.8% to 25.6%.
Ventilation	Incorporating heat recovery system with Mechanical supply and exhaust ventilation.	An average 13.6% saving of the total household power consumption.
Thermostat type	Installing programmable thermostat and applying energy star recommended setting.	An average saving of 14.7% from heating energy consumption.
Thermostat setting	Lowering indoor temperature by 1 degree centigrade during heating season.	An average saving of 3.43% of total household consumption.
Standby load	NA	An average 46.2 W per household
Energy saving lamp	Replacing every ILBs by energy saving lamps.	Saving of 13.62% to 17.06% of total household electric power consumption other than heating.
Supportive heating	Using wood as supportive heating.	Savings of 2.32 kWh in winter day consumption for each m^3 heating wood burning in a year.

The practical savings gained by the use of ground source heat pumps was lower than what manufacturers claimed. This might happened because of the extreme cold winter conditions creating frequent interference for electric resistance supportive heaters. Also, the most theoretical COPs were calculated to be best if the GSHPs are used for both the heating and cooling seasons which is less probable in Finland. The savings from installment of heat recovery systems with mechanical supply and exhaust ventilation was very encouraging. Also, an average stand by consumption of 46.2 W per household was calculated. The potential of savings after installment of programmable thermostats and following predefined settings accounted for about 14.7% of heating consumption. Arranging guidelines and controlling thermostat installations could help significantly improve the energy efficiency of households. The factors evaluated in this thesis are used for web-based household balance sheet calculator which gives the user personalized energy saving reccomendations.

One of the difficult situations in the analysis was attaining the effects of individual consumer electronics. The fact that there is an almost even distribution among all households blocked the pinpointing of the influence of individual electronic devices. The household basis load monitoring has taken a good step with installations of AMRs and, furthermore, reliable information and data is expected with incorporation of nonintrusive load monitoring systems with AMRs. Power companies can utilize the data from AMRs for more than billing purposes. They are able to engage fully in the process of load monitoring, creating energy saving awareness among customers and researches for efficiency actions.

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Appendix I: Household Questionnaire

HOUSEHOLD

BACKGROUND INFORMATION

1 How many persons are living in your household ?

0-7 age ________ 51-65 age ________
8-15 age ________ 66-75 age ________
16-30 age ________ 76 age or older ________
31-50 age ________

2 What kind of home are you living in?

☐ apartment house
☐ semi-detached house or row house ,which is ☐ Stone or brick made house
☐ one-family detached house ☐ Wooden houde

The energy class of the house if you know it ? ___________

3 Do you use your home most of yhe time
☐ Yes ☐ Yes, except summer months ☐ mainly Mon-Fri

4 When your house/apartment has been built ?
☐ 2000 or later ☐ 1990 –1999 ☐ 1980 –1989 ☐ 1970 –1979
☐ 1960 –1969 ☐ 1950 –1999 ☐ 1950 or earlier

5 With the help of the following statements we want to find are the heated areas in one building or do you have more buildings and what kind of heating system there is ? Cross the statements that are correct.

☐ living spaces are in one building
☐ living spaces are in two or more seperate building
☐ There is a warm garage in the house or its wing
☐ There is a cold garage in the house or its wing
☐ There is a sauna in the house
☐ There is a warm garage and/or stogare in the courtyard building
☐ There is a cold garage and/or stogare in the courtyard building
☐ There is a sauna in the courtyard building

6 The windows are ☐ double glazed ☐ triple glazed ☐ other, what ________________________

7 How many rooms there is in the main building of your home ? _____ (not include bathroon, WC,portc, etc.)

The number of the floors in your apartment ? ☐ one ☐ one and a half ☐ two ☐ three

8 The warmed area of your home (over 15 ℃)
☐ under 20 m² ☐ 20-40 m² ☐ 41-60 m² ☐ 61-80 m² ☐ 81-100 m²
☐ 101-120 m² ☐ 120-150 m² ☐ 151-200 m² ☐ over 200 m²

9 The warmed area of your home (5 - 15 ℃)
☐ under 20 m² ☐ 20-40 m² ☐ 41-60 m² ☐ 61-80 m² ☐ 81-100 m²
☐ 101-120 m² ☐ 120-150 m² ☐ 151-200 m² ☐ over 200 m²

10 The total square meter area of the courtyard and side buildings according to the stated heating levels, in case of electric heating
heated square meter area (over 15 ℃) circa ________ m²
semi heater square meter area (5 – 15 ℃) circa ________ m²

11 How many hours, on average, are people present in your home ?

a) weekdays
☐ 0-2 h
☐ 2-4 h
☐ 4-6 h
☐ 6-8 h
☐ 8-12 h
☐ 12-16 h

b) weekends
☐ 0-2 h
☐ 2-4 h
☐ 4-6 h
☐ 6-8 h
☐ 8-12 h
☐ 12-16 h

HEATING AND VENTILATION SYSTEMS

12 What is the primary heating system of your house?

- ☐ District heating
- ☐ Direct electric heating
- ☐ Electric storage heating
- ☐ Oil heating
- ☐ Wood heating with water circulation
- ☐ Other wood heating
- ☐ Ground source heat pump ,which power rating is ________ kW
- ☐ Other heating system, what? ________________________________

13 Do you have also other supportive heating system besides the previous?

- ☐ Wood heating (e.g. storing fire place) → How many times do you use it per week ? ________ times
- ☐ Solar power
- ☐ Air source heat pump , with a power rating of ________ kW
- ☐ Air/water heat pump ________
- ☐ Other heating system, what? ________________________________

14 Yearly use of fire wood in heating

If you can estimate you fire wood consumption in cubic meters of pile of wood, mark it down.
if you know the measure as (throw in) cubic meters, chance it to the pile of wood by dividing 1.6

Wood consumption is around ______ cubic meters of pile of wood

15 Underfloor heating

How many square meters of the underfloor heating have you implemented with electric cables? ________ m²

16 Do you have an automation system or other heating control, like Ouman's controller ?

17 Do you have indoor cooling system ? If yes, what?

- ☐ Air source heat pump
- ☐ Indoor air cooler, air conditioner
- ☐ Other, what? ________________________________

18 Ventilation of your house

- ☐ Natural ventilation without range hood
- ☐ Natural ventilation with range hood
- ☐ Mechanical exhaust ventilation
- ☐ Mechanical exhaust ventilation with exhaust heat pump
- ☐ Mechanical supply and exhaust ventilation
- ☐ Mechanical supply and exhaust ventilation with heat recovery
- ☐ Other, what

EQUIPMENT

19 Mark in the questionnaire the equipments that are in use at your household, how many and age of them.

- ☐ Refrigerator or other cool storage…………………… ______ units which over 10 years age ______ units
- ☐ Refrigerator + freezer box………………………….. ______ units which over 10 years age ______ units
- ☐ Freezer………………………………………………… ______ units which over 10 years age ______ units
- ☐ Chest freezer ______ units which over 10 years age ______ units
- ☐ Dishwasher, with drying cycle ☐ Yes ☐ No ______ units uses in a week ______ times
  - Is your dishwasher connected to? ☐ Cold water ☐ hot water ☐ I don't know
- ☐ Washing machine………………………………… using times in a month ______ times
- ☐ Washer-dryer……………………………………. using times in a month ______ times
- ☐ Tumble drier or equivalent ……………………………… using times in a month ______ times
- ☐ Drying cabinet…………………………………………. using times in a month ______ times
- ☐ Electric sauna stove…………………………………… using times in a week ______ times
- ☐ Electric sauna stove (open and use stove) ………… using times in a week ______ times
- ☐ Electric stove…………………………………………… using times in a week ______ times
- ☐ A computer with cathode-ray tube display ………… ______ units
- ☐ A computer with LCD display……………………….. ______ units
- ☐ A portable computer…………………………………… ______ units
- ☐ Cathode-ray tube television…………………………… ______ units
- ☐ LCD television…………………………………………… ______ units
- ☐ Home theatre system ______ units
- ☐ Other consumer electronics (DVD, Xbox, stereot, etc.) ______ units
- ☐ engine-block heater → In how many car ? ______ units Time per usage? ______ hour
- ☐ car's cabin heater → In how many car ? ______ units Time per usage? ______ hour

20 Lighting

Lighting (indoor lighting)		Lighting (outdoor lighting) If it affects your power consumption	
The number of bulbs	_____ units	The number of the bulbs	_____ units
The number of energy saving lamps	_____ units	The number of energy saving lamps	_____ units
The number of halogen lamp	_____ units	The number of halogen lamp	_____ units
The number of fluorescent lamp	_____ units	The number of fluorescent lamp	_____ units
Others	_____ units	Others	_____ units

Is lighting that is usually on when people are home, made by ? Mark one option

☐ incandescent bulbs ☐ energy saving bulbs ☐ fluorecent lamps ☐ energy saving lamps and fluorecent lamps

☐ incandescent bulbs and energy saving lamps ☐ energy saving and fluorecent lamps

ELECTRICITY COMSUMPTION HABITS

21 What is the indoor temperature of your house? ________ ºC ☐ I don't know
Have you thought about the possibility to lower your indoor temperarure? ☐ Yes ☐ No

22 Electronic devices have standby consumption, when they are not fully turn-off. Typical this kind of household machines are for example stereos, VCR, TV and computers.
How many of these machines do you have in your household ? ________ unit
How many of these do you switch off the standby state on daily basis ? ________ unit

23 Do you follow the size of your energy bill? ☐ Yes ☐ No

24 Would you like to follow your energy consumption through
☐ Internet-service (the hourly consuption of the previous day)
☐ From panel in your energy meter
☐ The bill is sufficient

25 Would you be willing to effect energy efficiency?
Changing driving/travelling habits ☐ Yes ☐ No Decreasing water usage ☐ Yes ☐ No
Changing bying habits ☐ Yes ☐ No Recycling ☐ Yes ☐ No
Decreasing other energy usage (devices) in your home ☐ Yes ☐ No

26 Would you be willing to take pricing that changes in periods, even hourly ?
☐ Yes ☐ No

27 Would you be willing to let a power company connect on and off your heating several times (for instance) during the day if that gave you a lower energy bill ? ☐ Yes ☐ No

28 Have you do any energy savings? If yes, what sort of ? For instance change main heating system (from that.to that) or change windows (some or all) or add insulation to frame work of the house.

____

____

____

29 Open feedback

____

____

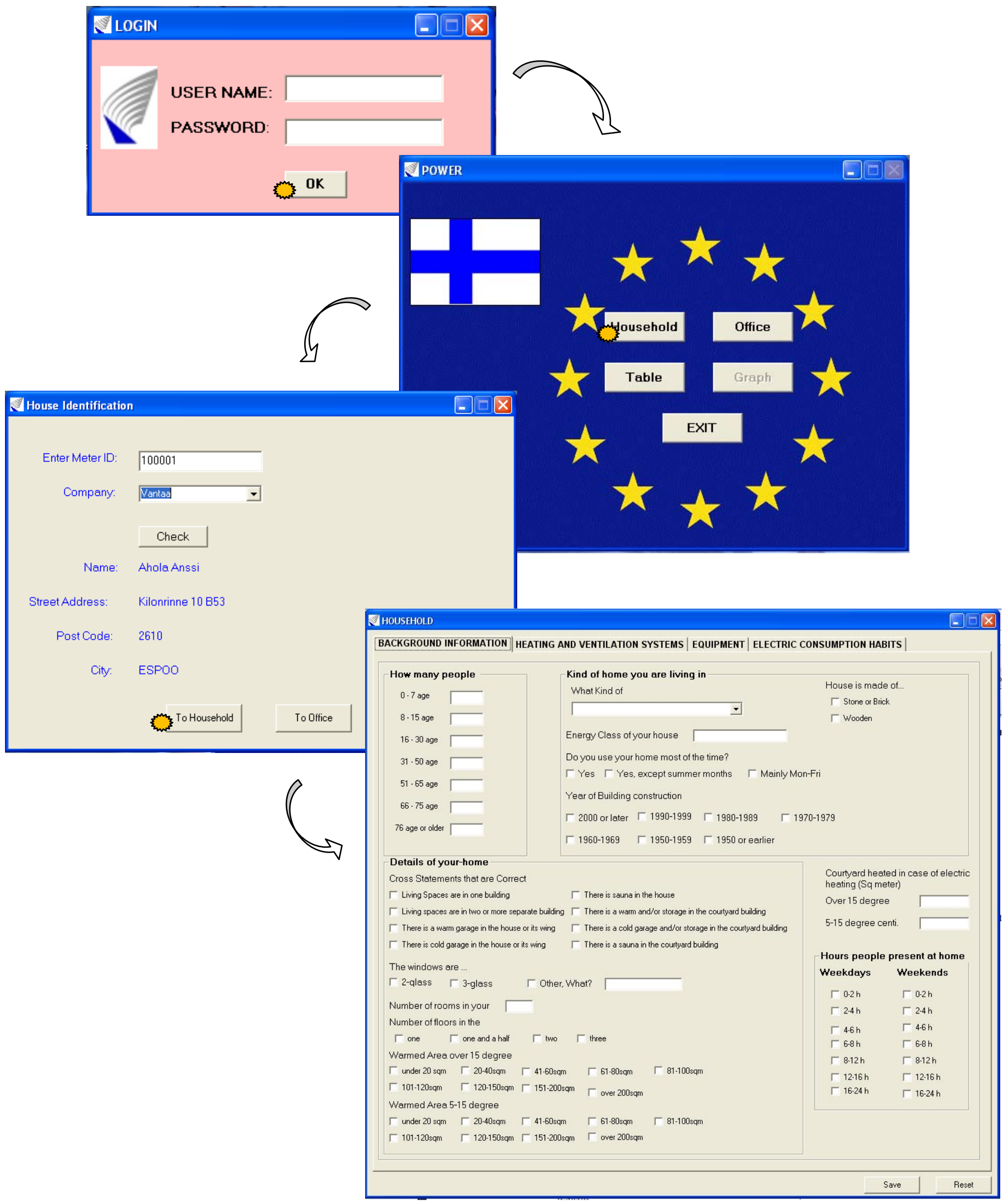
____

30 Would you be willing to take part in a research of the effects of the feedback to the energy consumption level?
The research will be made by VTT and Adato Energy Oy. ☐ Yes ☐ NO

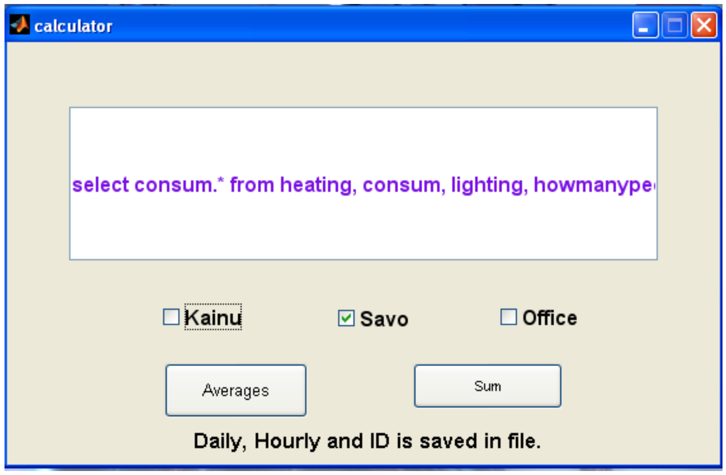
Thank you for your answers!

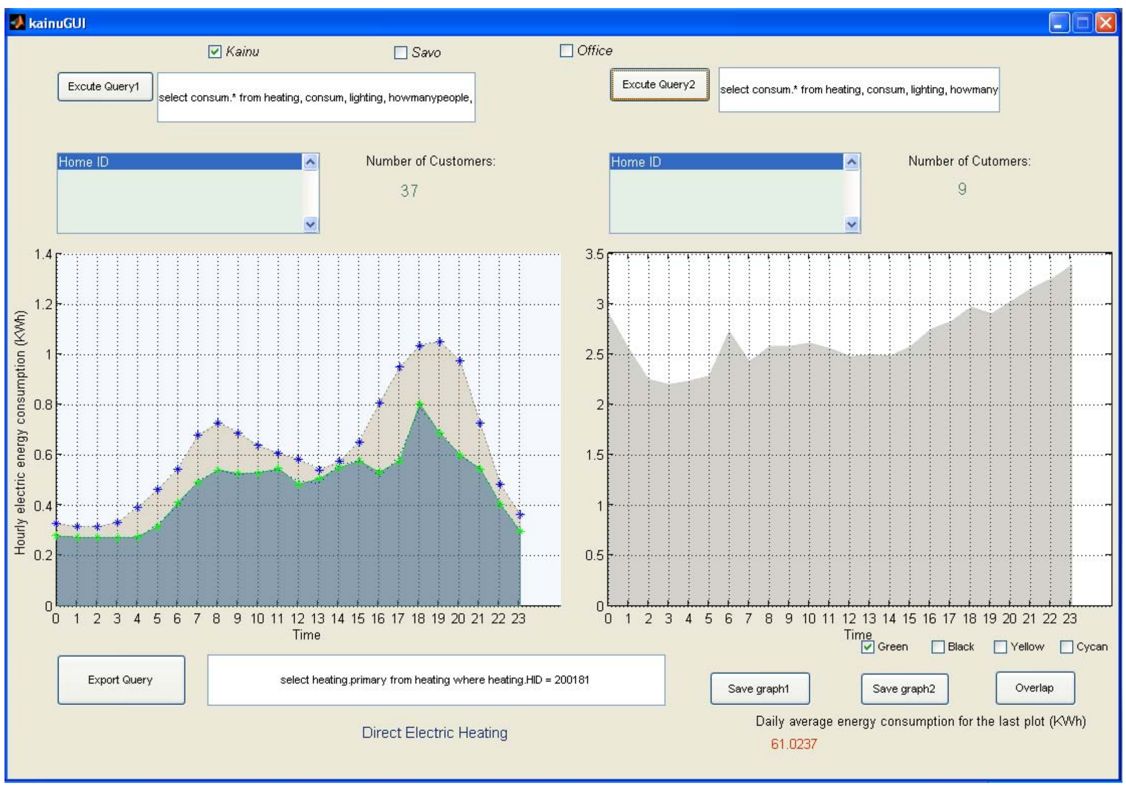
Appendix II: Programmed utilities deployed

Screen shoots of data entry program



Screen shoots of data analysis program





Appendix III: Overview of Statistical database

Table AIII-1: Number of households in database grouped by Primary heater type.

Primary heater	Kaajani	Savo	Vantaa	Total
Direct Electric Heating	823	283	38	1144
District Heating	538	273	841	1652
Electric Storage Heating	121	66	4	191
Ground source heat pump	27	64	0	91
Oil heating	375	46	4	425
Other wood heating	72	72	0	144
Wood heating with water circulation	89	52	0	141
Others	18	13	9	40

Table AIII-2: Number of households in database grouped by house construction material.

House made of	Kaajani	Savo	Vantaa	Total
Not answered	427	277	690	1394
Stone or Brick	488	130	145	763
Wooden	1148	462	63	1673

Table AIII-3: Number of households in database grouped by house construction year.

Const. Year	Kaajani	Savo	Vantaa	Total
Not answered	31	22	32	85
1950 or earlier	76	78	2	156
1950-1959	164	62	5	231
1960-1969	211	41	70	322
1970-1979	573	93	303	969
1980-1989	603	90	243	936
1990-1999	245	57	146	448
2000 or later	160	426	97	683

Table AIII-4: Number of households in database grouped by house type.

House type	Kaajani	Savo	Vantaa	Total
apartment house	172	211	685	1068
one-family detached house	1333	548	57	1938
semi-detached house or row house	522	99	154	775
unanswered	36	11	2	49

Table AIII-5: Number of residents of households in database grouped under age group.

Age group	Kaajani	Savo	Vantaa	Total
0 -7 age	322	263	122	707
8 -15 age	381	176	144	701
16 -30 age	512	234	253	999
31 -50 age	970	509	438	1917
51 -65 age	1473	599	552	2624
66 -75 age	700	237	197	1134
76 age or older	288	94	60	442
Total	4646	2112	1766	8524

Table AIII-6: Number of households in database grouped by heated area over 15 degree.

Heated area over 15 degree(sqm)	Kaajani	Savo	Vantaa	Total
under 20	1	1	2	4
20-40	47	33	83	163
41-60	224	154	285	663
61-80	349	125	274	748
81-100	388	116	188	692
101-120	543	106	41	690
120-150	359	179	15	553
151-200	124	113	4	241
over 200	28	41	5	74

Appendix IV: Overview of power consumption database

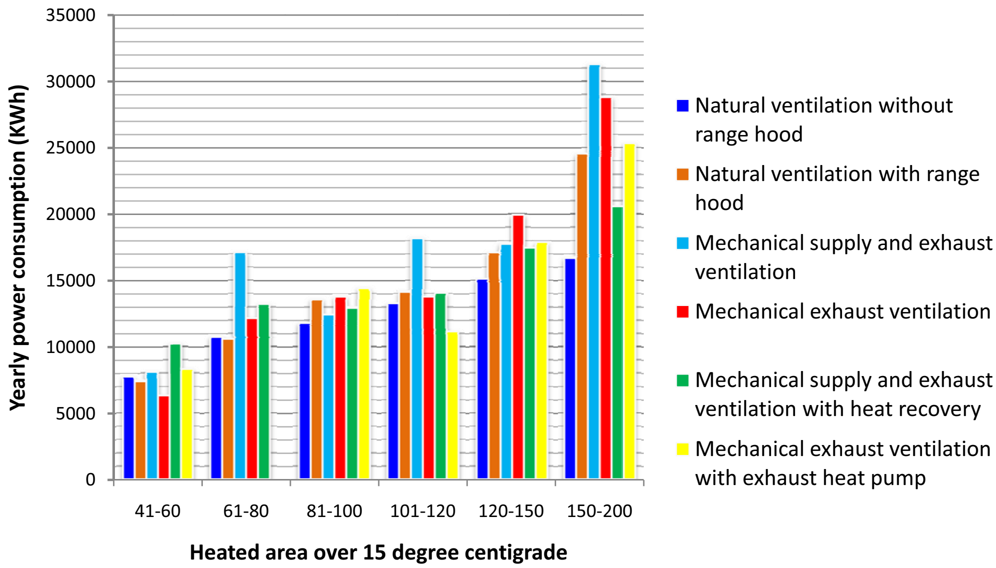


Figure A-1: Average yearly power consumption of direct electric heated houses grouped by heated area and ventilation type.

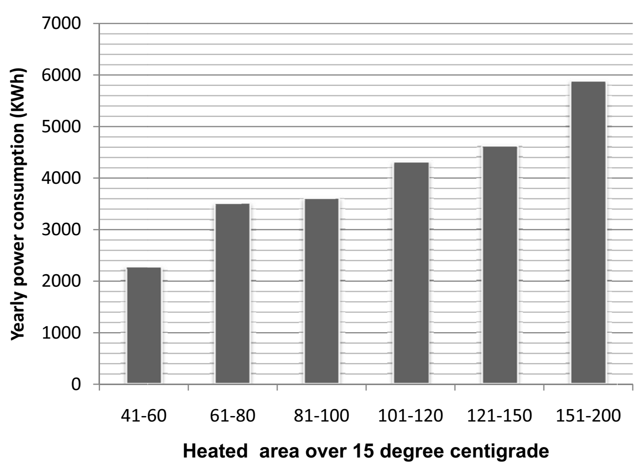


Figure A-2: Average yearly power consumption of district heated houses of natural ventilation with range hood system grouped by heated area.

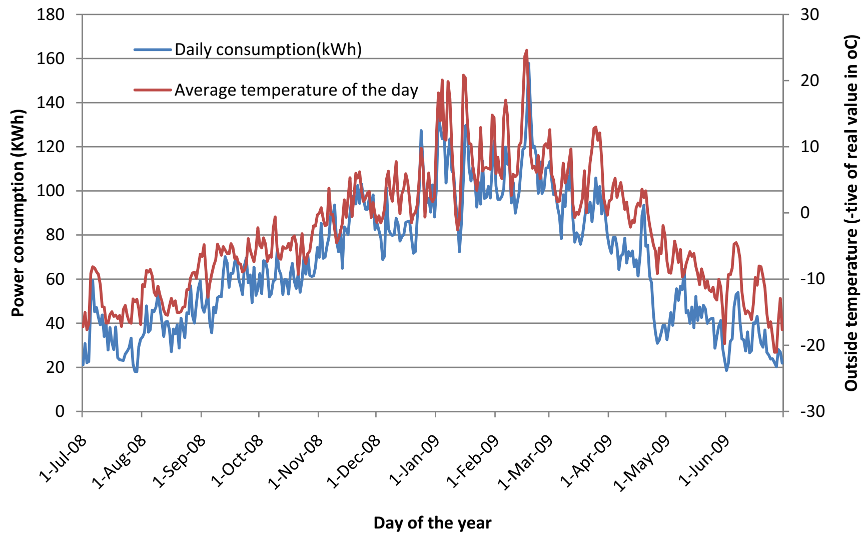


Figure A-3: Daily consumption and temperature whole year curve for typical direct electric heated household.

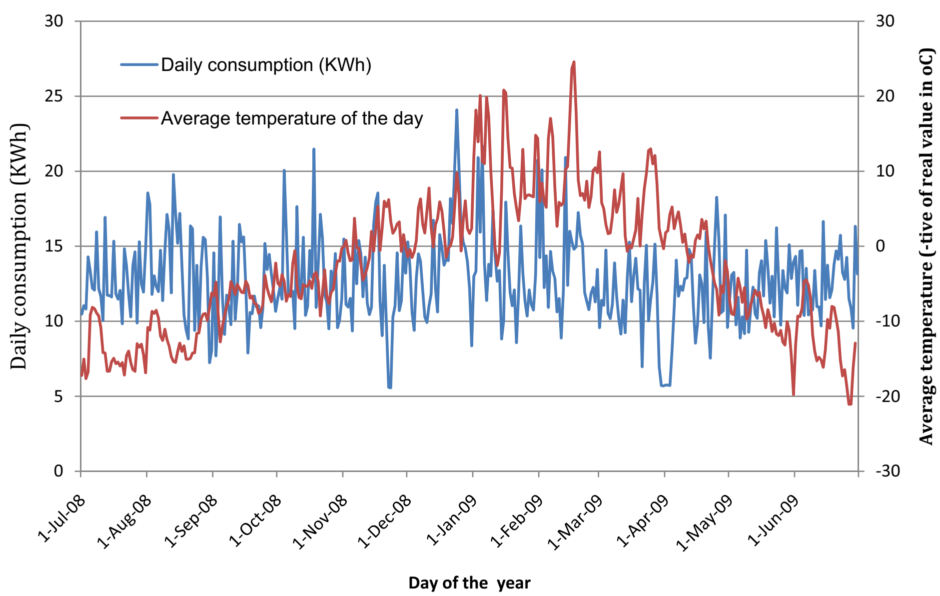


Figure A-4: Daily consumption and temperature whole year curve for typical household with district heating system.